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SHIPBOARD LED LIGHTING:
A BUSINESS CASE ANALYSIS

by

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December 2009

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SHIPBOARD LED LIGHTING: A BUSINESS CASE ANALYSIS

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LIST OF ACRONYMS AND ABBREVIATIONS

BCA:	Business Case Analysis
BES:	Budget Estimate Submission
CIC:	Combat Information Center
COTS:	Commercial off the shelf
CRI:	Color Rendering Index
C-T:	Color-Temperature
DARPA:	Defense Advanced Research Projects Agency
DESC:	Defense Energy Support Center
DoD:	Department of Defense
DOE:	Department of Energy
DSB:	Defense Science Board
DWCF:	Defense Working Capital Fund
EIA:	Energy Information Agency
FBCF:	Fully Burdened Cost of Fuel
GSA:	General Services Administration
HAZMAT:	Hazardous materials
LED:	Light Emitting Diode
MILSPEC:	Military specifications
NAVSEA:	Naval Sea Systems Command
NPV:	Net Present Value
OMB:	Office of Management and Budget
ONR:	Office of Naval Research
POM:	Program Objective Memorandum
PPBES:	Planning, Programming, Budgeting, and Execution System
PV:	Present Value

Ship Classes:

CG:	Guided Missile Cruiser
CVN:	Multi-purpose Aircraft Carrier (Nuclear-Propulsion)
DDG:	Guided Missile Destroyer
FFG:	Guided Missile Frigate

LCC: Amphibious Command Ship

LCS: Littoral Combat Ship

LHA: Amphibious Assault Ship (General-Purpose)

LPD: Amphibious Transport Dock

LSD: Dock Landing Ship

MCM: Mine Countermeasures Ship

PC: Patrol Coastal

SSN: Submarine (Nuclear-Powered)

SSBN: Ballistic Missile Submarine (Nuclear-Powered)

Sfc: Specific Fuel Consumption

SSDG: Ships Service Diesel Generator

SSL: Solid State Lighting

SSTG: Ships Service Turbine Generator

TCO: Total Cost of Ownership

WTI: West Texas Intermediate Crude Oil

I. INTRODUCTION

A. OVERVIEW

In an era of ever more constrained resources, the Navy must continually find new and innovative ways to squeeze the most performance out of every budget dollar. One way to achieve this is to maximize the cost effectiveness of existing weapons systems by lowering the total cost of ownership (TCO) over the life of a system. Use of this strategy can effectively free up resources for other operational or quality of life needs. Since the Navy's primary capital assets—its ships and submarines have such a long operational lifespan, investment decisions made today will either constrain the service or provide operational flexibility for years to come. This paper will explore one potential course of action for lowering TCO across the Navy Fleet, the implementation of Light Emitting Diode (LED) lighting technology onboard U.S. Navy ships and submarines. Once the total cost profile of shipboard LED lighting is understood, a better decision regarding implementation can be made. Shipboard LED lighting is an incremental lighting technology improvement that could provide cost savings for numerous Navy platforms. It should be one part of a comprehensive efficiency strategy for the fleet that could improve operational capabilities while increasing the quality of life and productivity of sailors.

B. SUBJECT OF THE BUSINESS CASE

This thesis is a Business Case Analysis (BCA) of the costs and benefits of LED lighting implementation onboard U.S. Navy surface ships and submarines. Implementation of LED lighting offers numerous potential advantages, despite its higher initial investment cost. These advantages include reduced maintenance requirements, operational fuel and energy cost savings, reduced need for shipboard spares, and improved quality of lighting. As a sustaining technological innovation, LED lighting improves upon current incandescent and fluorescent lighting systems. This BCA will include a financial analysis of the shipboard LED lighting, compared with the status quo,

to value the opportunity and determine what the Navy is missing. Additionally, barriers to implementation will be identified to determine why the Navy has not yet more fully adopted this technology.

C. RESEARCH QUESTIONS

The two primary research questions to be answered by this project are:

1. What are the potential costs and benefits of LED lighting installation aboard Navy vessels?
2. Why has it been difficult to implement shipboard LED lighting?

D. ORGANIZATION OF THE STUDY

Chapter II provides background material for this study, including a history of LED lighting, a detailed discussion of LED lighting for general illumination, the background of LED implementation in the Navy, and a discussion on fuel price trends. Chapter III presents the business case for LED lighting. Chapter IV discusses barriers to implementation, and Chapter V provides the conclusion and recommendations. Appendices A through D present detailed data supporting the BCA.

II. BACKGROUND

A. A BRIEF HISTORY OF LIGHT EMITTING DIODES

Light-emitting diodes (LEDs) are semiconductor devices that convert electricity into photons of light of varying frequencies, including the visible spectrum. Since the light is generated from a solid piece of semiconducting material (as opposed to a vacuum or gas tube in traditional incandescent and fluorescent lights), LED lighting is also called "solid-state lighting" (Gereffi & Lowe, 2008).

The light-emitting phenomena of semiconductors were first observed in 1907 by Marconi Labs researcher Henry J. Round. Working independently, Russian radio technician and scientist Oleg Losev made similar observations in the 1920s. He published 16 papers between 1924 and 1930, documenting comprehensively his study of the LED and outlining potential application for telecommunications. Unfortunately, Losev's work was largely forgotten due to World War II (Zheludev, 2007).

LED technology first became commercially available in the U.S. in the early 1960s, beginning in specialized applications such as lasers. Since LEDs emit light at a narrow range of wavelengths, the light they produce is not inherently white (unlike that generated by traditional sources) (Gereffi & Lowe, 2008). The color of LED light depends on the type of semiconducting material used. At first, white LED light was only possible by grouping red, blue and green LEDs together and controlling the current to each to produce an overall white light. In 1993, Nichia Corporation in Japan created a blue indium-gallium LED chip with a wavelength-shifting phosphor coating, allowing white light to be emitted from a single diode. Compared to the three-color solution, the single diode is much cheaper for the amount of light generated (ToolBase Services, 2009). Nichia's discovery of the white LED chip initiated the ongoing development by numerous firms to produce an LED product with high-quality white light suitable for general illumination (Gereffi & Lowe, 2008).

B. LED LIGHTING FOR GENERAL ILLUMINATION

LED lighting technology has some unique terminology. The actual light-emitting device, the LED "chip," is a very small piece of semiconducting material. The chip and other components are placed under an epoxy dome to form an LED "package." Groups of packages are clustered together in a housing, forming an LED lamp. Unlike traditional screw-in bulbs, LED lamps must be integrated into specially designed fixtures or "luminaires." Proper luminaire design, in particular thermal management, is a critical factor in operational efficiency and lifespan for LED lighting (Gereffi & Lowe, 2008). A simplified diagram of a typical LED package is shown in Figure 1.

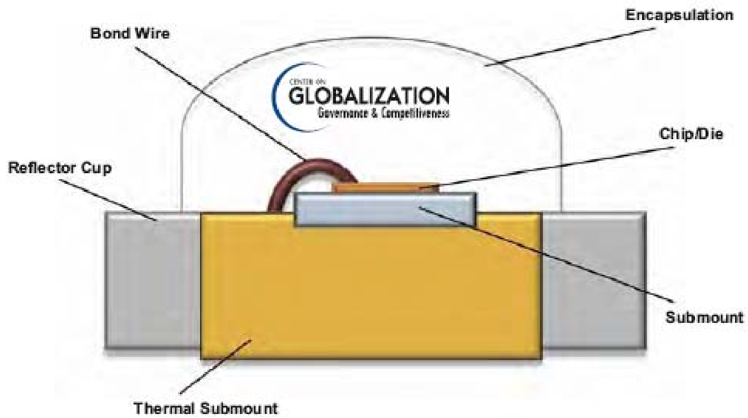

Figure 1. Typical LED package (from Gereffi & Lowe, 2008).

Thanks to gains in energy efficiency and improvements in material technology, the use of LEDs for general illumination has increased rapidly over the past several years. According to industry sources and energy experts, LEDs are now the most energy-efficient light source available. The major roadblock to wider adoption of LEDs is cost, typically more than five times as much as a comparable incandescent light source. However, LEDs use up to 85% less energy and last thirty times longer than incandescent bulbs. Compared to compact fluorescents, LEDs use half as much energy and last almost five times longer. Major manufacturers are targeting commercial and industrial markets first, where the higher upfront costs are offset by energy and maintenance savings. Typical customers leave their lights on almost 24 hours per day and pay labor charges each time a bulb must be changed. For these customers, the benefits of longer-lasting,

energy efficient LEDs are increasingly hard to ignore. As sales increase, economies of scale are expected to drive down LED costs, making them more attractive to residential customers as well. Current LED prices are decreasing by 25% per year. The Department of Energy projects that LEDs will make up 70% of the general lighting market in 20 years (Krieger, 2008). In 2007, the size of the global LED market was $4.6 billion. Sales of LEDs for general illumination represented an estimated 7% of this total, behind specialized applications such as mobile appliances, displays, and automotive uses. In recent years, sales have grown 40–60% annually, and are expected to reach $1.6 billion by 2012 (Gereffi & Lowe, 2008).

Figure 2 shows graphically the increasing performance of LED lights, as compared to traditional sources. LED performance has been increasing ten-fold per decade since the mid 1960s, and currently meets or exceeds that of most other existing lighting products (Craford, 2005).

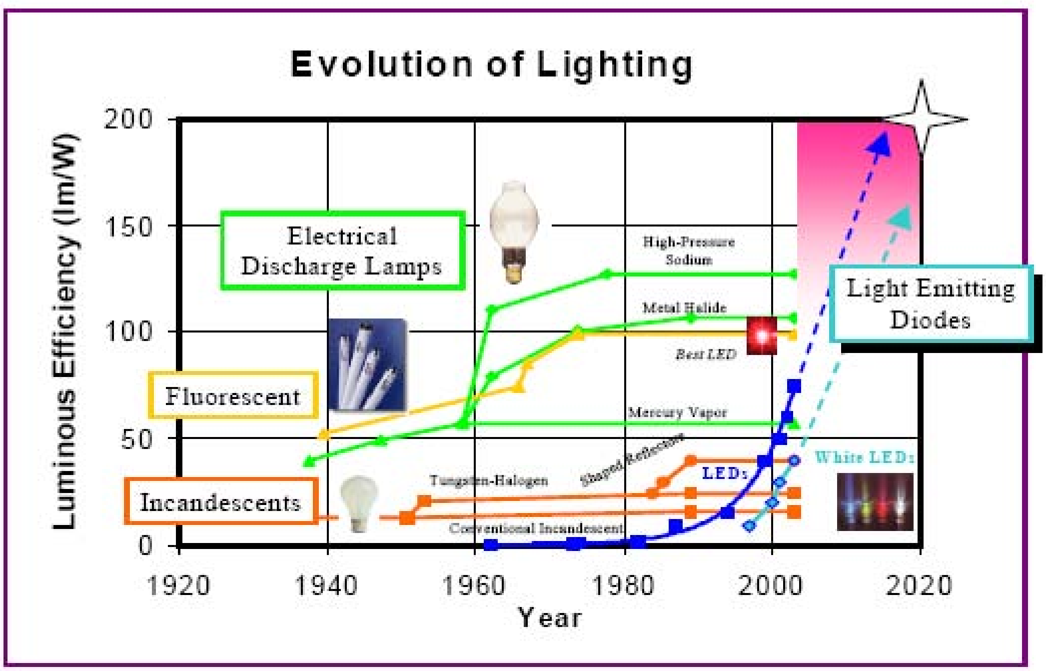

Figure 2. Projection of LED performance compared with conventional light sources (from Craford, 2005).

Table 1, adapted from ToolBase Services, an online resource for housing industry technical information, provides a concise overview of lighting terminology relevant to this research project.

Term	Definition	Units	Interpretation
Color Temperature (C-T)	The color of light	Kelvin (K)	Sunlight (at sunrise) = 1800K. 100W incandescent bulb = 2850K. Overcast sky = 6500K.
Color Rendering Index (CRI)	Light's effect on color	Scale of 0 to 100, with sunlight equal to 100	The higher the number, the "true" colors look in that light.
Brightness	The intensity of light	Lumens	Higher lumens = brighter light.
Power	Amount of electrical energy consumed.	Watts	Lower wattage = less energy consumed
Efficacy	The efficiency of the bulb to convert electricity into light.	Lumens per Watt	More efficient bulbs provide more light using less energy.

Table 1. Lighting terms and definitions (from ToolBase Services, 2008)

Table 2, adapted from various sources, provides a general comparison of incandescent, fluorescent, and LED lighting for five important performance variables. Cost figures, quoted from a residential builder, are included to show the relative order of magnitude increase and are not representative of any particular fixture compatible with Navy ship installation.

	Incandescent	**Fluorescent**	**LED**
CRI	100	62 - 82	92
C-T	2700 – 3300K	4100K	2500 – 6000K
Efficacy (lumens/watt)	12-15	50-100	60
Lifespan (hours)	1,000	10,000 – 20,000	50,000
Cost (residential lighting example)	$15	$35	$80

Table 2. Comparison of current lighting technology (from Mills, 2008, Krieger, 2008, Gereffi & Lowe, 2008)

As shown clearly in Table 2, LED lighting provides a much longer useful lifespan, better efficacy (energy efficiency) than incandescent and some fluorescents, and most closely matches the “warm” quality of light provided by incandescent bulbs (and sunlight). For LEDs, useful life is defined as the amount of time until 70% of the original light output is reached. Unlike incandescent bulbs, they do not burn out completely, but do suffer diminished output as individual LED packages fail within an array. Additionally, LEDs are inherently rugged and shock-resistant, a major benefit for most military lighting applications. The primary disadvantage is cost, with much higher upfront investment compared to other lighting options (ToolBase Services, 2009).

Heat generation is another area where LEDs offer benefits. Incandescent bulbs produce light by passing an electrical current through a metal filament until it glows.

They emit 90% of their energy as heat. In fluorescent bulbs, an electrical current is passed through gases, generating ultraviolet light which is converted to visible light by the phosphor coating on the inside of the tube. Approximately 80% of the energy emitted from a fluorescent tube is in the form of heat. LEDs produce light much more efficiently. A properly designed LED array is basically cool to the touch, with a small amount of heat transferred in the opposite direction by a heat sink. Additionally, LEDs generate light in a specific direction, while fluorescent and incandescent bulbs emit light and heat in all directions (DoE, 2009).

C. LED LIGHTING IMPLEMENTATION ONBOARD U.S. NAVY VESSELS

LED lighting has been considered for shipboard installation for over a decade. In a 1997 report, the Navy’s Affordability Through Commonality project outlined efforts to increase illumination levels onboard a Navy ship through the use of specular reflectors, or mirrored coatings, inside fluorescent fixtures. LED lighting was discussed as an interesting technology but was not considered powerful enough at that time for general illumination applications (Gauthier & Green, 1997).

In 2001, the Rocky Mountain Institute, an independent think-tank, studied energy usage by Navy surface ships and found numerous design inefficiencies leading to energy waste. They found that shipboard “hotel loads”—auxiliary systems such as pumps, chillers, and lights - consume nearly one-third of the Navy’s non-aviation fuel. They further calculated that each kilowatt-hour of electricity generated onboard a cruiser costs 27 cents, which is six times the rate paid for large customers ashore at that time. They concluded that retrofitting newer, more efficient systems, including lighting, could reduce energy costs for a typical cruiser by nearly $1 million per year (Lovins, 2001).

Several Defense Science Board (DSB) task forces (2001 and 2008) came to the same conclusions. They point out that reduced hotel load energy demands will free up electricity for new combat systems on existing platforms and be useful in future all-electric ships. These efficiency gains will provide operational benefits for many years

due to the long operational lifespan of ships. The DSB task force also noted that expected return on investment was even better in 2008 due to higher fuel prices (DoD, 2008).

The Defense Advanced Research Projects Agency (DARPA) initiated the High Efficiency Distributed Lighting (HEDlight) program in 2002, with the goal of increasing survivability, deployability, and maintainability of lighting systems onboard a ship. The concept called for remote source lighting with a central light-generating source coupled to a fiber optic distribution system to "pipe" light to various ship compartments. LED lighting was studied as one source of light generation and sea trials were conducted onboard a U.S. Navy destroyer (DARPA, 2009). While the remote source concept will probably not be adopted by the Navy, efforts such as the HEDlight program and other test installations have proven the reliability and effectiveness of LED lighting installation onboard ships. NAVSEA considers LED technology mature and an excellent candidate for transition to the entire fleet (NAVSEA, August 2008).

Continued advances in LED-based general illumination technology have intensified interest in shipboard applications for LED lights. Current incandescent and fluorescent fixtures are considered maintenance intensive and are a top ten maintenance item for the Navy's surface fleet. Vessels must dedicate shipboard storage space for replacement bulbs and fluorescent tubes must be treated as hazardous material (HAZMAT) waste, requiring special handling and storage until proper disposal facilities are available (Markey, 2008). Additionally, a typical fluorescent fixture has three points of failure—the bulb, ballast, and starter. These components increase the maintenance requirements for fluorescent fixtures. LED lighting offers a potentially ideal solution to these problems. With a much longer rated lifespan, shipboard maintenance requirements are reduced and space savings are achieved with a corresponding decrease in necessary spare parts. Disposal concerns are alleviated since LED arrays are not considered HAZMAT. LEDs also offer increased illumination levels and improved quality of lighting throughout a ship's life cycle.

A major step forward for shipboard LED lighting implementation was the August 2008 approval of the MIL-DTL-16377 supplement specification for solid state lighting

(SSL). This document supplements military specification (MILSPEC) MIL-DTL-16377H, the general specification for fixtures, lighting, and associated parts for shipboard use (NAVSEA, 2008). The SSL supplement removes a major roadblock for further development of shipboard-compatible LED lighting fixtures, as prior to this there were no defined standards for testing and configuration. The importance of the supplement cannot be overstated, since there is currently little standardization in the LED lighting industry. For instance, with no commonality of design current LED arrays are not interchangeable like traditional light bulbs. Publication of the SSL supplement establishes the Navy as a legitimate customer with a defined need, and will stimulate industry response to fill this need in the coming years.

Figure 3 provides a concise timeline of the Navy's shipboard LED lighting implementation efforts to date.

Figure 3. Navy Solid State Lighting Roadmap (from Markey, 2009)

D. OPPORTUNITIES FOR INNOVATION AND TRANSITION

To better understand how LED technology can best be implemented in the Navy fleet, it is useful to place it in a commonly used business framework. Christensen (2003) presents such a framework, based on a clear distinction between sustaining and disruptive technologies. While sustaining technologies can be radical or incremental in nature, they all improve the performance of established products. These performance benefits are seen in the normal areas that mainstream customers historically value the most. Disruptive technologies, on the other hand, are innovations that result in worse performance in the near-term. Disruptive technologies bring a different value proposition to the market; while initially underperforming, they bring a few features that new and fringe customers desire. Products based on this new technology are generally cheaper, easier to use, and simpler. Over time, as the sustaining technological improvements overshoot market needs, disruptive technologies improve to the point that they are fully performance competitive. At this point, they have expanded from their original niche application to dominate the existing market.

While some industry literature puts LED lighting in the disruptive category, it should be properly viewed as a sustaining technological innovation. It is currently not cheaper than existing systems, and while basic LED packages are simpler than conventional light bulbs, a significant amount of engineering for the luminaire is required to produce an acceptable end product. From the customer's point of view, light generation is an afterthought—as long as the proper light level exists, people generally do not care how it is generated. Considering LED lighting a sustaining technology may make the investment decision easier, since incrementalism is already ingrained in the DoD budgeting process.

The Navy has several ways forward to implement LED lighting across the surface and submarine fleet. The Office of Naval Research (ONR) funded the development of the SSL specification supplement through its Tech Solutions office. This program is designed to address fleet requests with near-term fixes, typically achieving turnaround in twelve months or less. A brief review of completed Tech Solutions projects on the ONR

website shows that most cost under two million dollars. Considering the large upfront investment required for LED installation on even a single ship, further funding through the Tech Solutions channel seems limited. ONR's SwampWorks program, with a focus on Fleet affordability and maintenance through technologies that significantly reduce maintenance practices and man hours on naval systems, may be a better choice for initial funding to implement LED lighting. However, regardless of the research and development umbrella program chosen, at some point LED lighting will require a true resource sponsor at the Pentagon level who can make shipboard implementation a priority for sustained funding.

E. UNCERTAINTY IN WORLD OIL MARKETS AND THE BURDENED COST OF FUEL

1. Historical Fuel Price Volatility and Future Trends

Predictions about the future price of oil are notoriously uncertain, but many experts contend that future decades will see continued price escalation and volatility. As seen in the 1973 Arab oil embargo and 1991 Gulf War, relatively small disruptions in the world oil supply can cause significant price fluctuations. The Arab oil embargo disrupted approximately four percent of world supply, but caused a substantial price spike and drove the U.S. economy into recession. If predictions of world peak oil production are accurate, the production peak and subsequent rise in prices will occur during the lifecycle of most current legacy weapons platforms. Therefore, it seems prudent to assume that energy costs will continue to rise over the foreseeable future and oil markets could very well experience high volatility as seen numerous times in recent history (DoD, 2008). Both the rising cost of energy and market volatility must be considered when conducting economic analyses of future programs.

The U.S. Energy Information Administration (EIA) publishes an annual outlook of energy prices, with forecasts out to 2030. In the *Annual Energy Outlook 2009*, the EIA presents a reference case with an oil price forecast for 2020 of $115 per barrel, rising to $130 per barrel in 2030. High and low price cases predict a price ranging from $50 to

a high of $200 per barrel. Diesel and gasoline prices are expected to rise approximately 1.04% per year through that time period. Rather than provide specific price targets, the EIA's monthly Short-Term Energy Outlook Supplement uses a confidence interval and several confidence levels in the forecast prices. The October 2009 report is typical of the wide range of future price uncertainty. The EIA tracks the prices of low-sulfur, light crude oil and uses West Texas Intermediate (WTI) prices as a benchmark. At the 95 percent confidence interval, January 2010 crude oil futures ranged from $42 to $124 per barrel. Narrowing the confidence interval to 68%, the price ranges from $55 to $95 per barrel. The 95% confidence interval for July 2010 futures is $38 to $152 per barrel. The fact that these confidence intervals are quite wide reflects the view of market participants that prices can change rapidly and increase or decrease dramatically in a short time period (EIA, 2009).

2. Measuring the True Cost of Fuel to Operational Units

The Department of Defense procures fuel through the Defense Energy Supply Center (DESC). DESC acts as a market consolidator and wholesale agent for DoD, managing the procurement and distribution of petroleum products from initial purchase to point of issue to military units. DESC establishes "standard prices" every fiscal year for all grades and types of fuel in order to insulate military services from marketplace volatility and simplify planning and budgeting. The standard price includes the raw commodity price plus a surcharge that covers storage, transportation and miscellaneous costs up to the point of issue. Swings in commodity market prices are absorbed by the Defense Working Capital Fund (DWCF). Since the DWCF operates on a break-even basis, net profit or loss is accounted for when setting future years' standard prices. Therefore, the standard price is typically a lagging indicator of the future price of fuel (DAG, Ch.3, 2009).

The standard price of fuel does not account for costs incurred by individual services to deliver the fuel from the DESC supply point to the ultimate consumer, operational units such as ships, aircraft and ground vehicles. This delivery cost is absorbed by each military service budget and is typically spread across multiple accounts,

hiding the actual cost of delivered fuel and making it difficult to compute. An unintended consequence of using the standard pricing practice is that the logistical cost of fuel delivery is considered free (DSB, 2001).

Due to the unappreciated burden of high fuel demand by operational forces, the true fiscal and operational cost for fuel is orders of magnitude higher than the commodity price commonly assumed. Efforts are underway to develop a new metric, the "Fully Burdened Cost of Fuel" (FBCF). The FCBF metric is particularly applicable to the acquisition analysis process since every dollar invested toward fuel efficiency directly impacts warfighter capability. DiPetto (2008) argues that DoD planning processes undervalue fuel and its delivery costs, and current DoD culture and business practices contain disincentives towards strategic investment. There is little incentive for program managers and program executives to create lifecycle operations and support savings through increased energy efficiency. Similarly, portfolio-wide investments that may benefit a wide range of platforms and systems are rarely considered. In the current climate of supplemental-based budgeting for wartime operations, fuel costs are considered the cost of doing business and are always paid by Congress. Finally, military logisticians excel at getting fuel to the warfighter, no matter where and no matter the risk, further insulating operational commanders from the true burdened cost of fuel. Expansion of FBCF usage in all levels of DoD planning and culture may help address these problems.

According to the Defense Acquisition Guidebook,

> The Fully Burdened Cost of Fuel is defined as the cost of the fuel itself (typically the Defense Energy Support Center (DESC) standard price) plus the apportioned cost of all of the fuel delivery logistics and related force protection required beyond the DESC point of sale to ensure refueling of this system. Estimates that include these logistics and protection costs may add from less than a dollar to over one hundred dollars to the per-gallon cost of the fuel. Hence, in some cases it is expected to help bring deeper Component or Enterprise consideration to a major source of DoD costs in a way that allows the Department to make more informed decisions. It is also a means for revealing some of the implications of design decisions made during the acquisition process that create a demand for logistics and which affect the "tooth to tail" ratio. The consequences of the large US fuel delivery "tail" have emerged from on-going

operations and as a key consideration in decision-making for systems development (Defense Acquisition Guidebook, May 2009).

Official analytic methods for determining FBCF are still in development, however, as of May 2009 the Defense Acquisition Guidebook presents an interim methodology outlined in Figure 4.

Fully Burdened Cost of Delivered Energy
- 7 steps to estimating cost elements

Step	Element	Burden Description
1	Commodity Cost of Fuel	DESC standard price for the appropriate type or types of fuel
2	Primary Fuel Delivery Asset O&S Cost*	Cost of operating service-owned fuel delivery assets including the cost of military and civilian personnel dedicated to the fuel mission.
3	Depreciation Cost of Primary Fuel Delivery Assets*	Measures the decline in value of fuel delivery assets with finite service lives using straight-line depreciation over total service life
4	Direct Fuel Infrastructure O&S and Recapitalization Cost*	Cost of fuel infrastructure that is not operated by DESC and directly tied to energy delivery
5	Indirect Fuel Infrastructure*	Cost of base infrastructure that is shared proportionally among all base tenants
6	Environmental Cost*	Cost representing carbon trading credit prices, hazardous waste control and related subjects.
7	Other Service & Platform Delivery Specific Costs*	Includes potential cost associated with delivering fuel such as convoy escort, force protection, regulatory compliance, contracting and other costs as appropriate.

* These costs vary by Service and delivery method (ground, sea, air)

Figure 4. Summary of FBCF Cost Considerations and Planning Steps (from Defense Acquisition Guidebook, Ch.3, 2009)

This general methodology is used as the basis for the fuel price sensitivity analysis presented in Chapter III.

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III. THE BUSINESS CASE FOR SHIPBOARD LED LIGHTING

A. SCOPE OF THE PROJECT

This study uses a cost-benefit structure to compare the life cycle costs of equipping the U.S. Navy surface and submarine fleet with LED lighting versus currently installed fluorescent lighting technology. There are a wide variety of shipboard lighting fixtures currently in the fleet; for instance, an Arleigh Burke-class destroyer has more than 25 different types of light fixtures. This project concentrates on general illumination fixtures, i.e., solid-state LED-equipped replacements for overhead fluorescent tube fixtures. Replacement of bunk and desk lighting, hangar bay lighting, external navigation lighting, and other specialty lighting will not be analyzed. General illumination fixtures account for approximately half of the total electrical lighting load on a typical ship and five percent of a ship's overall "hotel load" (which includes auxiliary systems such as seawater pumps, air conditioners, fans and lights). Cost savings through reduced energy demand and a reduction in maintenance requirements are the main expected benefits of LED fixture installation.

B. COMPARISON OF LED AND FLUORESCENT LIGHTING SYSTEMS

Figure 5 shows graphically the discounted total life cycle cost comparison between fluorescent and LED-based overhead lighting systems with baseline assumptions. These costs are for conversion of each ship class to the new LED lighting system. The figure provides an overview to aid in deciding which classes to convert first. Life cycle costs for each individual class assume the full initial fixture cost with a subsequent decrease in cost due to learning curve related savings.

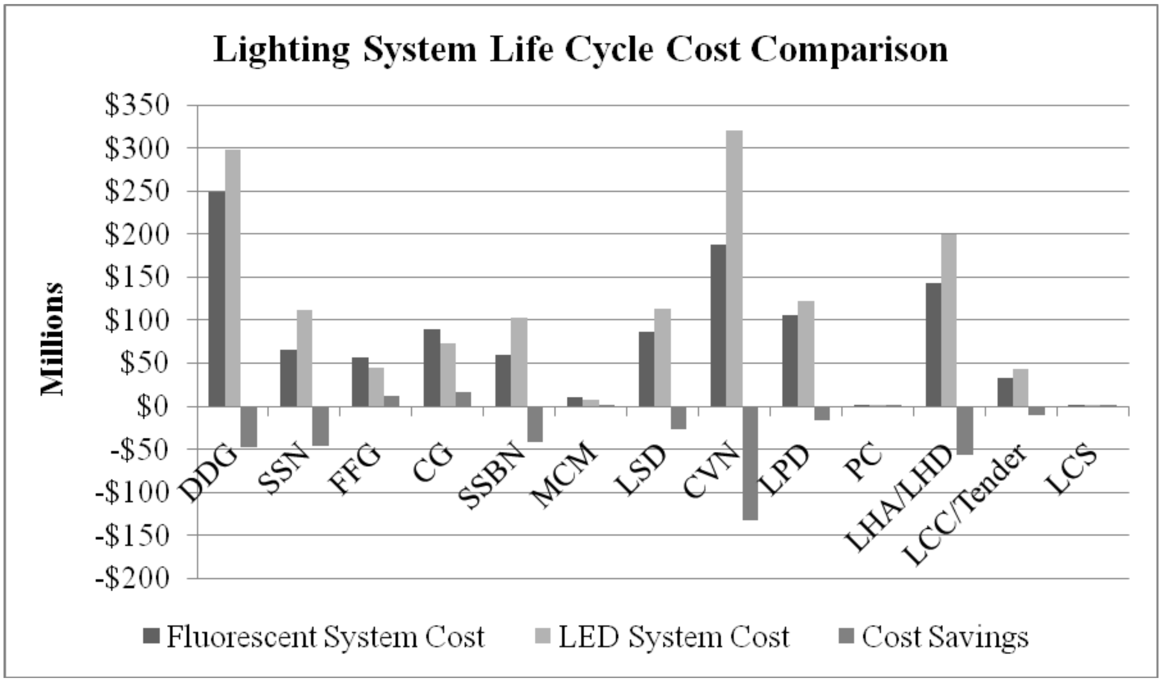


Figure 5. Lighting System Life Cycle Cost Comparison Summary

As can be seen from Figure 5, with baseline assumptions outlined in subsequent sections, LED lighting systems are currently only cost effective for five ship classes: FFG, CG, MCM, PC and LCS. These are the same classes with LED fixture break-even costs above $1300 as shown in Figure 6. Key cost assumptions are varied in the sensitivity analysis section to refine thresholds for fleet affordability. Table 3 summarizes the cost to convert a single ship in each class to LED lighting, the payback period, and savings associated with the installation of an LED lighting system using the baseline assumptions.

Single Ship Costs and Savings			
Class	Cost of LED Installation ($M)	Payback Period (Years)	30-year Life Cycle Cost Savings ($M)
CG	1.18	16	0.76
FFG	0.52	12	0.42
MCM	0.21	15	0.13
LCS	0.67	23	0.12
PC	0.05	14	0.03
SSN	0.94	30+	-0.87
DDG	2.11	30+	-0.87
LPD	4.48	30+	-1.46
LSD	3.92	30+	-2.19
SSBN	2.50	30+	-2.34
LCC/Tender	4.46	30+	-2.46
LHA/LHD	9.43	30+	-6.29
CVN	12.84	30+	-12.00

Table 3. LED Installation Cost and Savings by Individual Ship

C. METHODOLOGY

A baseline scenario is developed that analyzes the conversion of the Navy fleet to LED-based general illumination. Based on the National Naval Vessel Register's list of active ships in commission, a 249-vessel fleet is analyzed. Since the high initial cost of LED lighting makes it prohibitively expensive to outfit all vessels in a single year, a phased purchase approach is presented that assumes learning curve-related savings as the number of LED fixtures procured increases. For analysis purposes, the fleet is separated into 13 different basic ship types, and a detailed cost-benefit analysis is conducted for each ship class over a 30-year expected operational life. Sensitivity analyses are conducted on the key cost drivers of LED fixture cost, number of fixtures per vessel and price of fuel. Risk considerations and non-quantifiable benefits associated with the adoption of a new technology also are presented.

Appendix A provides more details for the baseline scenario with the financial analysis of fleet conversion to LED lighting. Appendix B contains detailed fixture count

calculations for all 13 ship classes. Appendix C details learning curve calculations used for the cost of LED fixtures. Appendix D includes detailed cost/benefit calculations for all thirteen individual ship types.

Four cost factors will be considered when analyzing the overall lifecycle cost of each lighting system. These are:

1. Cost of investment—the initial purchase cost for LED fixtures, plus labor costs to install fixtures, and cost to purchase and install replacement LED fixtures due to lamp mortality.

2. Cost of maintenance—includes labor to replace burned out lamps or defective components and material costs for replacement lamps and components.

3. Cost of operations—the cost in dollars to run each shipboard lighting system for one year.

4. Cost of disposal—the cost to properly dispose of hazardous waste contained within lamps or fixture components.

Once all individual cost factors are calculated, they are summed to compute the total lifecycle cost of each lighting system over the 30-year life of a typical Navy ship. To account for the time value of money, the annual subtotaled costs are multiplied by a discount factor to compute the Present Value (PV). The total Net Present Value (NPV) of each system is then calculated by adding the initial investment cost to the total discounted annual costs. NPV allows the comparison of different alternatives over a given timeframe of analysis in terms of current dollars. Since cost savings are the ultimate goal, the lighting system with the lowest NPV is the proper investment choice.

NPV is calculated using the following formula:

$$NPV = C_0 + \Sigma(C_t / (1 + r_t)^t)$$

where C_0 is the initial investment cost (year zero cost), t is time in years, C_t is the cost in subsequent years (t), and r is the discount rate (Brealey, Myers, & Allen, 2008, p. 37). A real discount rate of 2.7% is used in this analysis, based on 2009 Office of Management

and Budget (OMB) Circular A-94 guidance on conducting benefit-cost analysis of federal programs. Real discount rates have the inflation premium removed and are used in cost-effectiveness analyses (OMB, 2008).

D. ASSUMPTIONS

The following major assumptions are made for the purposes of life cycle cost comparison between solid-state LED and fluorescent fixtures:

<u>Investment</u>:

- The current cost of a new LED overhead fixture is assumed to be $1300, and it is assumed this cost will decrease along a 95% learning curve as more fixtures are purchased. Since there are no Navy-approved LED general illumination overhead fixtures currently in production, this cost is an estimate based on a hybrid fluorescent/LED hangar bay fixture installed on several Navy amphibious ships. This assumption is reasonable because the majority of the hybrid fixture cost is due to the LED components (B. Schoch, personal communication, September 24, 2009).
- General illumination light fixture counts are approximated for each ship class and were derived from source material provided by Naval Sea Systems Command. Ship classes were grouped in one of three categories (older combatants, newer combatants, and amphibious ships), and fixture counts were approximated from samples in each category. In general, newer combatants such as the Arleigh Burke-class destroyer appear to have more light fixtures for a given hull displacement than older ships. Appendix B contains more detailed information on how these fixture counts were derived.
- Three types of fluorescent overhead light fixtures are installed on Navy ships—designated symbols 331.1, 77.4 and 333.1. These correspond with

Military Specifications MIL-DTL-16377/8, /11 and /12, respectively, and are one, two and three lamp fluorescent fixtures with 20-watt T12 fluorescent lamps.

- New LED fixtures are a form/fit replacement for currently installed fluorescent overhead fixtures. All general illumination fluorescent fixtures are replaced by LED fixtures on a one for one basis. Total investment cost includes the cost of the fixture plus one hour of average labor time to install.

- Civilian shipyard workers will install the new LED fixtures. A $350 man-day rate ($43.75/hour for a typical 8-hour day) is used to calculate the cost of installation, based on a study conducted at Pearl Harbor Naval Shipyard, Hawaii (Hunt, 2003).

<u>Operations</u>:

- LED fixtures draw one quarter of the electrical load of comparable fluorescent fixtures (Toolbase.org, 2009, B. Schoch, personal communication, October 1, 2009).

- Shipboard lighting systems account for 10% of the total electrical generator load onboard a typical gas turbine destroyer (Krolick, 1981).

- The Defense Energy Support Center (DESC) fiscal year 2010 standard price of naval distillate fuel (F-76) is $2.77 per gallon (DESC, October 2009).

<u>Maintenance</u>:

- The average lifespan of T12 fluorescent lamps is 9,000 hours and the lifespan of LED arrays is 50,000 hours. Assuming continuous operation, this equates to 1.02 years for fluorescents and 5.7 years for LEDs (Hunt, 2003, and Markey, personal communication, 2009). This study rounds these numbers to 1 and 5 years, respectively.

- The fluorescent lamp change out process lasts an average of 30 minutes (including problem diagnosis and travel time from workcenter to job site and back). Two people, in the pay grades E-1 to E-4, will be required to complete the work. FY2010 DoD military personnel composite standard pay and reimbursement rates for these four pay grades are averaged and used for total dollar amount per unit of time.
- The average cost of replacement lamps, starters, and ballasts were retrieved from the General Services Agency GSA Advantage Web site and are current as of 30AUG09.
- Since both lighting systems will require periodic inspections as part of preventative maintenance, this cost is not considered in the analysis.

Disposal:

- Fluorescent lamps must be handled and disposed of as hazardous material (HAZMAT). An average disposal cost for government activities of $0.05 per linear foot is used in the cost calculation (DoD, May 2003).
- LEDs are assumed to have no restrictions on disposal and therefore have no associated annual disposal cost.

E. COST CALCULATIONS

1. Cost of Investment

Fluorescent fixtures require no upfront investment cost since they are already installed on all active Navy ships.

The initial investment cost for LED fixtures is significant; therefore, a phased purchase approach is used that assumes learning curve-related savings as the number of LED fixtures procured increases. The first ships to be converted should be those that break-even at current fixture prices of $1300 or higher. As shown in Figure 6, these are the CG, FFG, MCM, PC and LCS classes. Additional classes should be converted in following years in the sequence shown in Table 4.

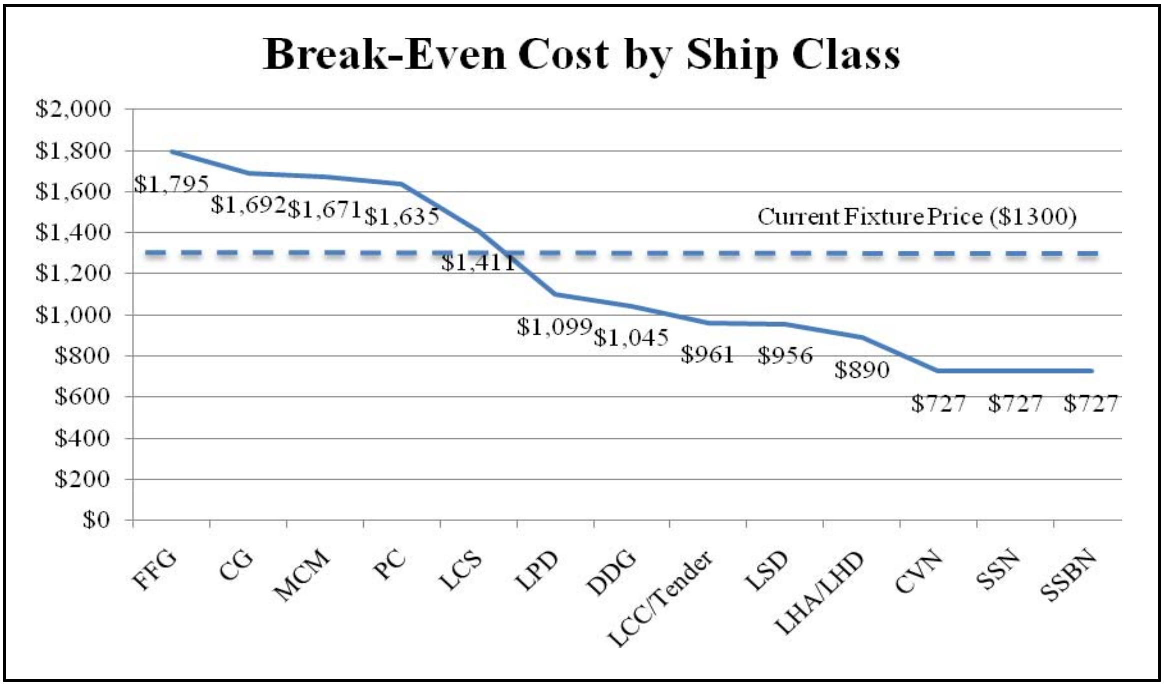


Figure 6. LED Fixture Break-Even Cost by Ship Class

5-Year LED Fixture Purchase Sequence								
Year	Class	Number	Percent of Navy Fleet	Total Number of Fixtures	Break-even Cost per Fixture	Total Ships Converted	Total Fixtures Purchased	Cumulative % Fixtures Converted to LED
1	FFG	30	12.05%	11520	$1,795			
	CG	22	8.84%	19382	$1,692			
	MCM	14	5.62%	2142	$1,671			
	PC	10	4.02%	350	$1,635			
	LCS	1	0.40%	502	$1,411	77	33896	7.8%
2	LPD	11	4.42%	36685	$1,099			
	DDG	55	22.09%	86515	$1,045	66	123200	36.2%
3	LCC/Tender	4	1.61%	13268	$961			
	LSD	12	4.82%	35028	$956			
	LHA/LHD	9	3.61%	63135	$890	25	111431	61.8%
4	SSN	53	21.29%	36888	$727			
	SSBN	18	7.23%	33552	$727	71	70440	78.0%
5	CVN	10	4.02%	95550	$727	10	95550	100.0%
	Total:	249		434517		249	434517	

Table 4. Purchase Sequence for LED Fixtures

In addition to the cost of the new fixtures, a labor rate must be factored in for removal of the legacy fixtures and replacement with new LED fixtures. For this analysis, a labor rate of $350 per man-day ($43.75 per hour) is used, based on Hunt's 2003 study.

LED fixtures fail gradually, and individual LED packages are not replaceable. At the end of their 50,000-hour average lifespan, all LED fixtures will be replaced. This is more cost effective than attempting to replace internal components due to greatly decreased labor requirements during the replacement process. Although not modeled in this study, the used fixtures would also have some salvage value. Current literature states that LED prices are expected to fall 25% per year, similar to price drops seen in the semiconductor and flat screen television industries (Krieger, 2008). Therefore, these recurring investment costs are expected to decrease over a typical ship's 30-year lifespan. The baseline scenario assumes a conservative 95% learning curve, which is typical for electronics manufacturing (NASA, 2008). Table 5 shows the declining cost of LED fixtures as increased numbers are produced. Calculations using 93% and 90% learning curves are discussed in the sensitivity analysis section later in this chapter.

Replacement LED Fixture Costs						
Year	95% Learning Curve	Average Unit Cost (95%)	93% Learning Curve	Average Unit Cost (93%)	90% Learning Curve	Average Unit Cost (90%)
1	$1,300	$950	$1,300	$868	$1,300	$783
6	$497	$496	$334	$333	$181	$180
11	$473	$472	$311	$310	$163	$162
16	$459	$458	$298	$297	$153	$153
21	$449	$449	$289	$289	$146	$146
26	$442	$441	$282	$282	$141	$141

Table 5. Cost of replacement LED fixtures

2. Cost of Maintenance

Annual maintenance costs for fluorescent lighting systems includes labor to replace burnt-out lamps and material cost of replacement lamps and components. Ship's personnel will conduct labor at the rate of $29.29 per hour, or $0.49 per minute, based on

the fiscal year 2010 Department of the Navy average composite standard pay rates for E-1 to E-4 personnel. Table 6 summarizes the military labor rate calculations used in this study.

Military Pay Grade	Annual DOD Composite Rate
E-1	$44,472.00
E-2	$48,943.00
E-3	$54,661.00
E-4	$64,966.00
Average	$53,260.50
Avg. Hourly Rate	$29.29

Table 6. Military Standard Composite Pay Rate Calculation

Assuming a one-year lifespan for T12 fluorescent lamps, all lamps will be replaced each year. Each job requires two personnel and lasts on average 30 minutes. A 2004 survey of the lighting repair process onboard USS George Washington (CVN 73) found that the average time to change a fluorescent lamp or starter was 86 minutes. Given the various sizes of Navy ships being analyzed, the assumption of 30 minutes of average time per lamp replacement seems conservative. Any defective fixture components are replaced while changing out lamps and are assumed to require no additional labor time.

Fluorescent light fixtures include two additional components, starters and ballasts. New starters are installed each time a lamp is replaced. Based on both Hunt's 2003 report and the CVN 73 report, approximately 6% of ballasts can be expected to fail each year. This study assumes a cost of $3.95 per replacement T12 lamp, $1.00 per starter and $12 per T12 magnetic ballast, which are the average minimum prices retrieved from the GSA Advantage website as of August 31, 2009.

LED fixtures are considered to be maintenance free for the duration of their useful lifespan. This analysis assumes that new LED fixtures for each vessel will be purchased every five years, as outlined under the cost of investment section above.

3. Cost of Operation

The cost to operate fluorescent and LED lighting systems is calculated based on the amount of fuel used by the ship's service generators. A typical Navy surface combatant conducts numerous underway training exercises and one six-month deployment every two years, averaging 23 days at sea per month while deployed and 9 days at sea per month while non-deployed. The ship will spend on average 300 days underway over the course of this two-year operational cycle, or 150 days underway per year. 85% of the underway time (20 hours per day) is at cruise steaming conditions (Weekes, 2003). This amounts to 3000 hours of operation per year, about in the middle of the peacetime-wartime range of 2400 to 3300 hours average for surface combatants during fiscal year 2004 (Webster, et al., 2007). These assumptions are used for all ship classes. It is further assumed that one ship service generator is always offline as a standby unit, decreasing the total generators used in calculations by one.

For conventionally powered ships with ships service gas turbine generators (SSTGs), fuel consumed per day is calculated using the following formula:

$$Fuel_{gallons}=(sfc*power*time)/(8.33*746)$$

Sfc is specific fuel consumption (lbs./hp-hr), power is the electrical load on the SSTG in watts, and time is in hours. 8.33 is a conversion factor to convert from pounds to gallons and 746 is used to convert from horsepower to watts. Sfc at a 1.5 megawatt average load per SSTG is .61 lb/hp-hr and sfc at 1.3 megawatts is .67 lb/hp-hr. (Weekes, 2003). Gallons of fuel consumed per hour are calculated by setting time equal to one hour in the above formula. Fuel consumption directly attributable to shipboard lighting systems is calculated by taking 10% of this total (Krolick, 1981). Overhead general illumination fixtures account for approximately half of the total lighting system energy use, so this total is halved to arrive at the gallons of fuel used by each generator for overhead fluorescent lighting.

Seven ship classes addressed in this study use ships service diesel generators (SSDGs) instead of gas turbine generators. Fuel consumed for these classes was approximated from data retrieved from the Caterpillar Marine Power Systems website.

Hourly fuel consumption for these generators was then used in the same manner outlined above to calculate approximate fuel consumed by the shipboard overhead fluorescent lighting system on each ship. Table 7 summarizes generator fuel usage for each conventionally powered ship class.

Class	Name	Service Generator	Number of Generators	Output (KW)	Approx. fuel consumption (gph)
AUX	Blue Ridge	SSTG	3	1300	140.2
	Emory S. Land	SSTG	3	1300	140.2
DDG	Arleigh Burke	SSTG	3	3000	147.2
FFG	Perry	SSDG	4	1100	71
CG	Ticonderoga	SSTG	3	3000	147.2
MCM	Avenger	SSDG	3	375	25
LSD	Whidbey Island	SSDG	4	1300	80.5
	Harpers Ferry	SSDG	4	1300	80.5
LPD	Austin	SSTG	4	3000	147.2
	San Antonio	SSDG	5	2500	150
LHA/LHD	Tarawa	SSTG	4	1300	140.2
	Wasp	SSTG	4	1300	140.2
LCS	Freedom	SSDG	4	750	49
PC	Cyclone	SSDG	1	150	11

Table 7. Conventional Ships Service Generator Fuel Consumption

The operational cost of lighting systems on nuclear powered vessels is considered to be zero for the purposes of this study, since electricity is essentially “free” when produced by a nuclear reactor. This is a critical assumption for the CVN, SSN, and SSBN classes, since it removes operational costs from consideration and makes maintenance and disposal costs the key factors for lighting system comparison.

An LED lighting system draws one quarter of the electrical load of a fluorescent system (Schoch, B., personal communication, October 1, 2009). Therefore, using the same method outlined above, the operational cost for the LED lighting system on each conventional ship class is one-fourth the amount of the fluorescent system.

4. Cost of Disposal

The disposal cost for fluorescent lights is $0.05 per linear foot (DoD, May 2003). Assuming all fluorescent lamps are replaced annually and each lamp is 2 feet long, the cost of disposal is simply the number of lamps times two multiplied by $0.05. This does not take into account the cost to store burned out lamps onboard the ship until reaching port, taking up space that might otherwise be used more effectively.

LEDs have no restrictions on disposal with normal waste and therefore have no annual disposal costs.

F. RISK/BENEFIT ANALYSIS

1. Risks

There are several risks associated with implementation of LED-based lighting systems onboard Navy ships. Despite the fact that LEDs have been in use for over fifty years, the use of LEDs for general illumination is a relatively new application of this technology, and represents only a small fraction of the overall LED market. As an early adopter, the Navy would have to absorb higher upfront investment costs. With no guarantee that other agencies or commercial entities will follow suit, the assumed cost decreases in future years may not materialize if the customer base does not continue to grow. Additionally, because there are no comparable systems currently in operation and little historical data from test installations, there could be hidden costs not captured in this analysis.

2. Qualitative Benefits

In addition to the benefits of lower maintenance, operation and disposal costs, there are numerous non-quantifiable (qualitative) benefits associated with the implementation of an LED lighting system. Unlike fluorescent lighting, LEDs are fully dimmable and can operate from a backup battery in the case of electrical power interruption. LEDs contain no mercury, which would be released in the event of fluorescent lamp breakage (Hunt, 2003). Due to their much longer operational life, LEDs require little to no space for storage of spares and no space for storage of burned out

lamps awaiting disposal. For a destroyer-size ship, approximately 400 cubic feet of space would be freed up for other uses. A decrease in cooling requirements would be realized due to the reduced heat output of LEDs, resulting in even more fuel savings and lower operational costs through reduced loads on shipboard cooling systems (Markey & Zalewski, 2008).

Many sources claim LED lighting is superior in quality to fluorescent lighting. It is perceived as being less harsh and, depending on the selection of LED chip, emits a warmer color light that is generally accepted as more pleasing to the eye. LED light also renders colors closer to sunlight than fluorescent light. This benefits shipboard personnel by providing better color perception and causing less eyestrain. LEDs emit light in a focused beam, allowing for task-specific lighting where needed with little spillover. LED fixtures could be designed that can change color with a controller switch, alleviating the need for current colored windows and baffles or separate standalone fluorescent fixtures for red and blue light. Cyan colored LED lights are also much more compatible with night-vision devices, eliminating the blooming and halo effect encountered with incandescent and fluorescent lamps. Combined, these properties make LED lighting ideal for installation in light sensitive areas, such as a ship's hangar bay, well deck, or Combat Information Center (CIC).

G. SENSITIVITY ANALYSIS

1. The Cost of LED Fixtures

a. The Cost Curve for LEDs – Is There Value in Waiting?

As noted previously, current industry experts estimate that LED prices will decrease approximately 25% per year as production increases and the installed commercial base grows. This cost is for the individual LED packages and not the additional circuit boards and drivers that make up the entire light fixture. Since the Navy is not a large consumer of LEDs compared to many commercial activities, quantity discounts would not necessarily be significant. The Navy would order a very specific, purpose-built fixture, and systems integrators who design and deliver these fixtures in compliance with military specifications would not necessarily pass along savings.

Additionally, if the Navy waits too long for commercial technology to mature, the major lighting manufacturers who could produce the desired fixtures would be entrenched in much larger commercial markets, and would have little incentive to enter the relatively smaller defense market. Therefore, a waiting strategy is not in the best interest of the Navy if it desires to take advantage of LED lighting technology.

b. Learning Curve Sensitivity Analysis

Break-even LED fixture cost for each class is presented in Figure 6. In order further analyze fixture price sensitivity the learning curve assumption will be varied. The baseline scenario assumed a conservative 95% learning curve for the cost of future year LED fixture production beyond year one. The following tables summarize the impact on life cycle cost of a single ship in each class if 93% or 90% learning rates are assumed. For both tables, the installation cost is the discounted investment cost over a 30-year operational life, which assumes five complete replacements of LED overhead light fixtures.

Life Cycle Investment Cost with 93% Learning Curve			
Class	Cost of Life Cycle LED Installation ($M)	Payback Period (Years)	30-year Life Cycle Cost Savings ($M)
CG	2.71	12	1.24
FFG	1.18	10	0.63
LCS	1.54	15	0.39
LPD	10.26	29	0.33
MCM	0.47	13	0.21
PC	0.11	13	0.04
DDG	4.84	30+	-0.03
SSN	2.14	30+	-0.50
LSD	8.98	30+	-0.63
LCC/Tender	10.20	30+	-0.68
SSBN	5.73	30+	-1.34
LHA/LHD	21.58	30+	-2.53
CVN	29.40	30+	-6.88

Table 8. Life Cycle LED Investment Costs (Assuming a 93% Learning Curve for LED Fixture Production)

The assumption of a 93% learning curve decreases the payback period on the five currently affordable classes and makes the life cycle savings for the LPD class positive as well.

Life Cycle Investment Cost with 90% Learning Curve			
Class	Cost of LED Installation ($M)	Payback Period (Years)	30-year Life Cycle Cost Savings ($M)
LPD	7.83	19	1.96
CG	2.07	10	1.67
LCC/Tender	7.78	24	0.94
LHA/LHD	16.46	28	0.89
FFG	0.90	9	0.81
LSD	6.85	24	0.79
DDG	3.69	20	0.74
LCS	1.18	13	0.64
MCM	0.36	10	0.28
PC	0.08	10	0.06
SSN	1.63	30+	-0.16
SSBN	4.37	30+	-0.43
CVN	22.42	30+	-2.22

Table 9. Life Cycle LED Investment Costs (Assuming a 90% Learning Curve for LED Fixture Production)

The assumption of a 90% learning curve further increases the cost savings realized with LED fixture installation. With this assumption, all conventionally powered ship classes show positive life cycle cost savings. Nuclear powered vessels, with no operational fuel costs, still do not show any savings.

It is important to note that even under the most conservative learning curve scenario, LED fixture prices can be expected to drop steeply within the first few years. For instance, an initial lot size of just 1,000 fixtures drives the final unit cost down to approximately $780. This means that outfitting even a handful of ships per year, at a slower pace than the plan presented in this BCA, is enough to establish a production base and benefit from learning curve related savings.

2. The Number of LED Fixtures

In addition to the high initial cost of the LED fixtures, the number of lighting fixtures per ship is a significant cost driver and one of the main reasons only a small portion of the fleet achieves cost effectiveness in the baseline scenario. Although fixture counts for each ship class are estimated based on the most accurate data available, they are still approximations. Therefore, a closer look at this variable is warranted. Varying the fixture counts by ten percent does not change the cost savings for any class from negative to positive or vice-versa. For the five conventional classes that show negative cost savings in the baseline scenario, a break-even fixture count was computed as shown in Table 10.

Class	Baseline Fixture Count	Break-Even Fixture Count	Percent Reduction for Break-Even
DDG	1573	1285	18.28%
LSD	2919	1201	58.85%
LCC	3317	1394	57.98%
LPD	3335	2196	34.15%
LHA/LHD	7015	2091	70.19%

Table 10. Fixture Counts Required for Break-Even

In general, these findings show that a lower number of light fixtures per ship is better (in terms of cost-effectiveness). Partial installations may also be desirable to take advantage of potential cost savings while waiting for fixture prices to decrease to a more acceptable level. Fixture count data collected for DDGs showed that approximately 300 of the 1573 fixtures per ship are series 331.1 (single lamp) fluorescent fixtures. Comparing this to the break-even counts above, replacing just the two and three-lamp fluorescent fixtures onboard DDGs with compatible LED fixtures would make financial sense while reducing the requirements for fluorescent lamps to a minimum. A detailed review of light fixture data for other ship classes may reveal similar partial installations opportunities.

3. The Cost of Fuel

a. Historical and Future Oil Prices

The prices of crude oil and refined petroleum products have historically been very volatile. Small disruptions in the overall world oil supply, such as those caused by the Arab oil embargo in the 1970s and first Persian Gulf War in 1991, typically result in large price swings in world oil markets. The U.S. Energy Information Agency's (EIA) Annual Energy Outlook 2009 predicts that oil prices will rise over the long term, with an 80% increase in the average price per barrel by 2030. The EIA addresses volatility by presenting a high price case (with a 170% increase) and a low price case (with a 30% decrease). Prices of diesel fuel are predicted to increase an average of 1.4% per year through 2030 (EIA, 2009).

Holding all other assumptions constant but increasing the cost of fuel by 1.4% each year results in a modest increase in cost savings for FFG, CG, MCM, PC and LCS classes. These are the same classes that break even at the current fixture price of $1300. Since operational fuel costs rise proportionately for both lighting systems, no new ship classes reach the break-even threshold with this change. Perhaps more interesting is the effect of market volatility on fuel prices. Assuming a fuel price of $4.99 per gallon (80% higher than the 2010 standard price) results in positive life cycle cost savings for the DDG and LPD classes. If fuel prices reach $6.51 per gallon, the Navy fleet as a whole reaches the break-even point (with cumulative cost savings of zero). Fuel cost savings in the first seven LED-equipped ship classes fleet are great enough at this price to offset the high installation costs for the larger ship classes and lack of operational savings for nuclear-powered vessels. Assuming a fuel price of $7.48 per gallon (170% higher than the standard price) results in positive life cycle cost savings for all conventional ships except the LHA/LHD class. If fuel prices fall to $1.94 (a 30% decrease in the standard price), only four ship classes (FFG, CG, MCM, and PC) have a positive life cycle cost savings with LED lighting system installation. Table 11 summarizes the break-even fuel cost by ship class. Holding all other assumptions constant, at fuel prices above those listed LED lighting systems are more cost-effective than fluorescent systems.

Class	Break-Even Fuel Price (per gallon)
FFG	$1.48
CG	$1.64
MCM	$1.68
PC	$1.74
LCS	$2.40
DDG	$4.07
LPD	$4.21
LCC/Tender	$6.59
LSD	$6.73
LHA/LHD	$9.29
SSN	n/a
SSBN	n/a
CVN	n/a

Table 11. Break-Even Cost of Fuel by Ship Class

b. The Fully Burdened Cost of Fuel

The fully burdened cost of fuel is defined as the cost of fuel itself (the DESC standard price) plus the apportioned cost of all the logistics and force protection requirements for fuel delivery to an operational unit. Various studies have estimated that it can add from one to over $100 to the cost of a delivered gallon of fuel (DoD, 2009). There is currently no standardized or approved method for calculating the Navy's fully burdened cost of fuel (FBCF). The DiPetto (2008) presentation suggests that the burdened cost is five to fourteen times the purchase cost, for ground and air force units. Strock and Brown (2008) provide numbers from a 2007 Naval Sea Systems Command study showing the burdened cost to be 1.58 times the DESC standard cost. This study incorporates a fuel burden factor to assess burdened fuel cost effects on the operational cost of both lighting systems. It is assumed that Navy ships would have a lower FBCF than ground or air units. Smaller ship types that typically operate in the littoral regions (MCM and PC) are assumed to refuel pierside and are assigned a constant fuel burden factor of one. All other conventional classes are assigned a fuel burden factor of 1.58, and this is varied up to 3.0 to assess LED lighting system affordability in increasingly

burdened scenarios. Table 12 and Figure 7 summarize the effects of increasing fuel burden on an individual ship's life cycle cost savings with LED lighting installed.

Fuel Burden Factor:	1.58	2	2.5	3	
Class	Cost Savings ($M)	Cost Savings ($M)	Cost Savings ($M)	Cost Savings ($M)	Break-Even Burden Factor
CG	$1.85	$2.63	$3.57	$4.50	0.59
LPD	$0.17	$1.35	$2.75	$4.15	1.52
DDG	$0.21	$1.00	$1.93	$2.87	1.46
FFG	$0.94	$1.32	$1.77	$2.22	0.53
LCS	$0.67	$1.06	$1.53	$1.99	0.87
LCC/Tender	-$1.42	-$0.67	$0.22	$1.11	2.38
LSD	-$1.30	-$0.66	$0.11	$0.87	2.43
MCM	$0.13	$0.13	$0.13	$0.13	0.61
PC	$0.03	$0.03	$0.03	$0.03	0.63
LHA/LHD	-$4.74	-$3.62	-$2.28	-$0.95	3.35
SSN	-$0.87	-$0.87	-$0.87	-$0.87	n/a
SSBN	-$2.34	-$2.34	-$2.34	-$2.34	n/a
CVN	-$12.00	-$12.00	-$12.00	-$12.00	n/a

Table 12. Life Cycle Cost Savings per Ship with Varying Fuel Burden Factor

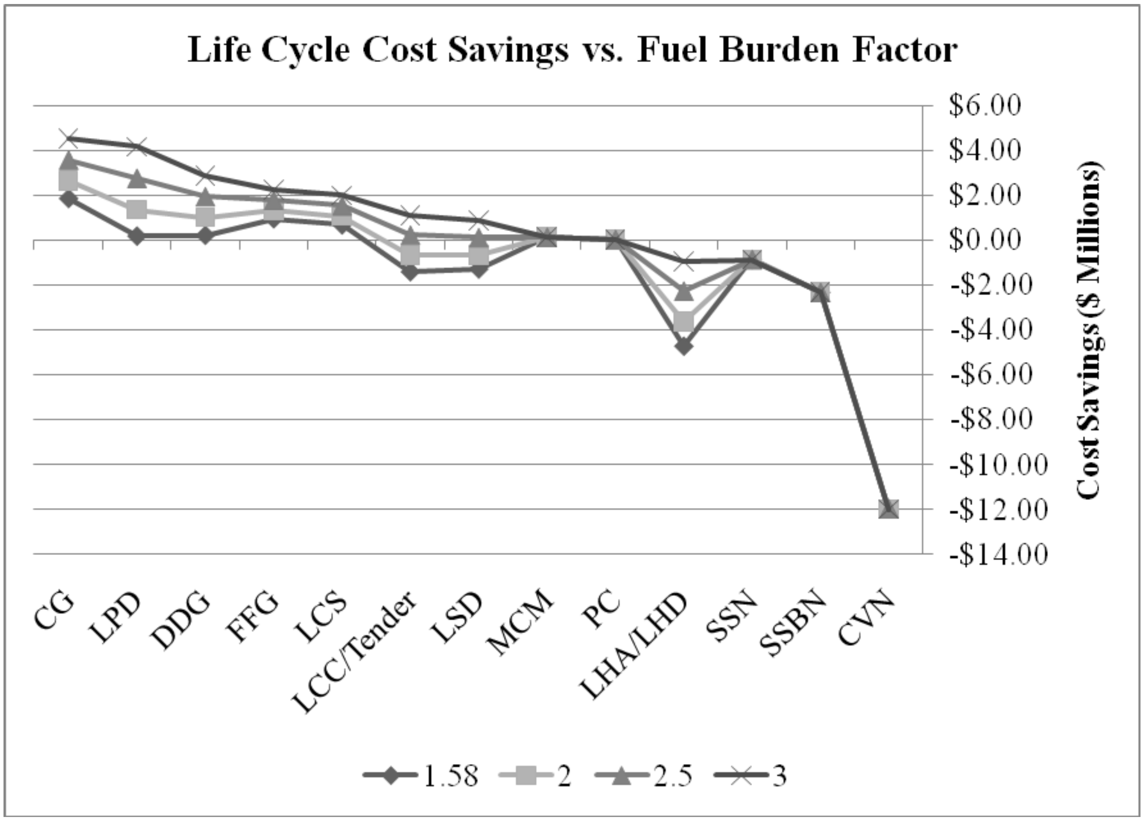


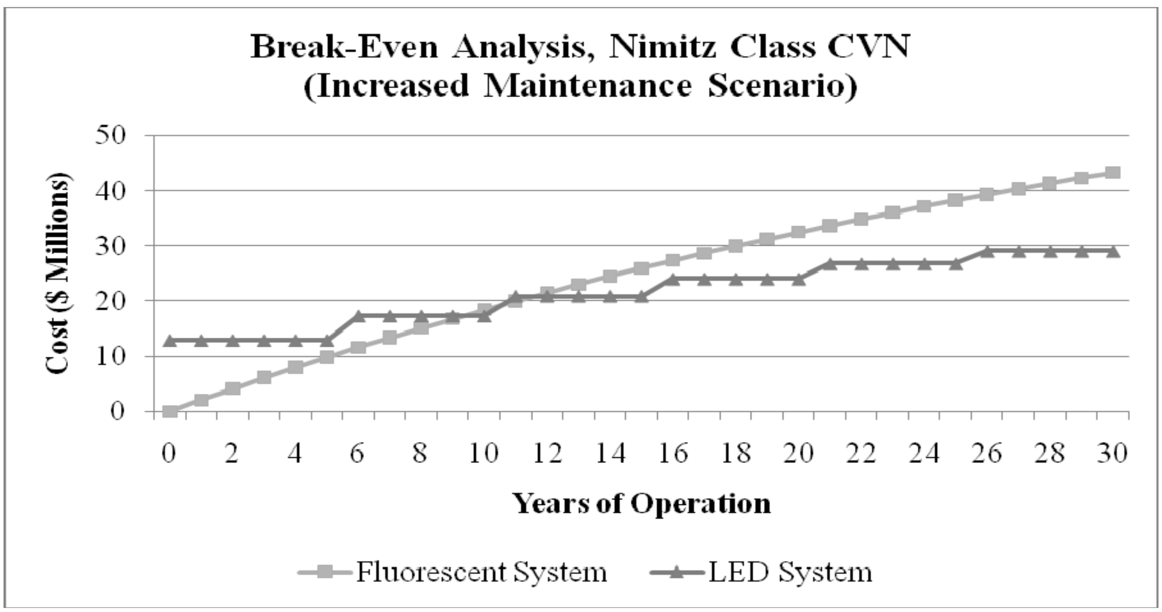
Figure 7. Life Cycle Cost Savings by Ship with Varying Fuel Burden Factor

As can be seen in both charts, increasing the fuel burden factor increases the operational fuel cost savings for all classes except nuclear powered vessels. As the fuel burden factors are adjusted, payoffs for LED lighting system installation change. At fuel burden factors above 2.5, LED installation on all conventional ship classes except the LHA/LHD results in positive cost savings over a 30-year ship life cycle.

4. Alternative Maintenance Scenario for Aircraft Carriers

A 2004 report on the lighting repair process onboard USS George Washington (CVN 73) found that while the annual expenditure on material costs was low (approximately $10,300), a large amount of man-hours were needed to conduct lighting system maintenance (approximately 26,454 hours per year). The average time spent on lighting-related electrical trouble calls ranged from 68 minutes to replace diffuser windows to 261 minutes for fluorescent ballast change outs. Of the 913 total trouble calls, 830 resulted in a fluorescent lamp or starter replacement. These averaged 86

minutes. In order to assess the true cost of maintenance man-hours, maintenance hours per lamp change are adjusted to 1.42 (2.8 times more than the baseline scenario assumption). Results for the CVN class are presented in Figure 8. The NPV for the LED system is much more attractive in this case, with a total life cycle cost savings of approximately $14.2M and payback achieved in year 12. Since this is based on a single data point, the results should not be considered definitive. Perhaps a more effective use of manpower or adoption of a comprehensive relamping strategy could reduce the cost of fluorescent lighting system maintenance. However, further study is certainly warranted to determine if LED lighting installation onboard aircraft carriers can indeed achieve these dramatic cost savings.



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$37,088,522	$0	$0	$0	$37,088,522	***$29,070,847***
Fluorescent	$0	$63,674,711	$0	$71,663	$63,746,374	*$43,311,134*

Figure 8. Alternative CVN Life Cycle Cost Analysis

IV. BARRIERS TO IMPLEMENTATION

A. UNDERSTANDING THE VALUE PROPOSITION

The Navy must fully understand the value of LED lighting over the life cycle of its main capital assets in order to make the right investment. This business case presents assumptions and a purchase plan that allows implementation of this technology at the lowest cost. In addition to the operational and maintenance savings, LEDs offer extra intangible benefits as outlined by Freymiller (2009) in a companion study. Fully understanding these benefits and including them in the purchase decision is essential.

The value of LED lamps comes from their extreme long life and increased energy efficiency, which leads to lower total cost of ownership for any platform so equipped. By focusing on these facts and amortizing the expense over a platform's long operational lifetime, the high initial cost is easier for decision makers to rationalize.

The value proposition must also be understood at the system level, as opposed to just the unit level. Individual commanders who reduce energy costs are often penalized with reductions in future budget cycles. Furthermore, acquisition investment decisions are hampered by the artificially low standard fuel price and lack of a system-wide level of analysis. Specific capability improvements from innovative efficiency technologies are generally considered at the individual platform level. A broader view of total force improvement due to the increased warfighting benefits of an entire inventory of efficient platforms could materially change many investment decisions (DoD, 2001).

B. FACTORS THAT FACILITATE INNOVATION

A 2009 RAND study provides a useful construct for conceptualizing innovation in an organizational setting. Drezner (2009) provides the following list of factors or conditions that facilitate innovation:

- Institutional or regulatory environments that encourage new concepts
- Early adopters who are willing to buy and use initial versions of the innovation
- Potentially significant product demand

- High potential payoff
- Minimal barriers to entry

The institutional environment provides a critical foundation for innovation. Bureaucracies, such as DoD and the Navy, tend not to be naturally innovative, since they are designed to enforce standardized procedures rather than develop new ideas and concepts. In this context, sustaining innovations, such as LED lighting, have a better chance of transition to the end user than disruptive ones that upset the entire system. Early adopters are needed to take the innovation from the lab to operational users, refining the product along the way and demonstrating its utility. The Navy and DoD have generally done a good job in this regard. As the only buyer for many new technologies, DoD sometimes accepts a high first cost in order to shape future research and development as it sees fit. High demand for the product establishes a market with high enough sustainable sales to justify the initial investment. From a vendor's point of view, the existence of a commercial application for their products is a large factor in their decision to partner with DoD. Since the initial investment in many innovation implementation scenarios entails risk, there must be a high enough payoff, in terms of system performance, to justify the Navy's investment. Finally, low barriers to entry allow firms to establish a new market niche and provide competition for DoD business.

The Navy must address each of these factors when implementing innovative technological solutions such as shipboard LED lighting. In many cases, this will mean working with small businesses that are well suited for niche production of specialized products.

C. SPLIT INCENTIVES

The DSB Task Force (2001) found that DoD budgeting practices generally act as a disincentive towards greater investments in energy efficient technologies. The funding to make platforms more efficient comes from acquisition accounts, but the benefits of lower operating costs accrue to the operations and support accounts. This split incentive mechanism can impair an efficiency-improving program's chances of winning short-term budget battles. According to Dahut (2008), using Total Cost of Ownership analysis can

help bridge the gap between acquisitions and operations accounts and strengthen budget justifications, which are critical to obtaining program funding. This is particularly relevant in the current budget environment, where the trend seems to be static or declining budgets for the foreseeable future.

D. LIFE CYCLE COSTS

During the course of several background interviews, it became apparent that program offices do look at best value propositions when considering the life cycle costs of investments in new programs. For existing programs in the operations and sustainment phase, however, retrofit plans or life cycle cost reduction arguments are not necessarily appealing. Managers typically consider one to two year efforts, and many aging platforms rely on band-aid fixes to get by. For instance, the P-3 mission computer is already four years beyond the end of its service life, but the platform will probably continue in operation for at least the next decade. However, the engineering and development effort that would be required to adapt a replacement commercial off the shelf (COTS) computer for use would be unjustifiably large. Since future funding is already in place for the follow on P-8, there is little incentive to pour large amounts of money into the existing platform (Carty, J., personal communication, August 2009). The installation of LED lighting onboard ships that are already decades old presents a similar situation, so arguments must be prepared that justify the expense over the remaining life of the ship.

E. INSTITUTIONAL AND ORGANIZATIONAL BARRIERS

The defense budget of the United States is one component of a larger Federal Budget process. The DoD budget has a large domestic impact and is subject to public scrutiny and much debate. These pressures shape the ultimate outcome of the defense budget each year and result in a highly complex budgeting process. DoD uses the Planning, Programming, Budgeting and Execution System (PPBES) to formulate the defense budget. Current DoD PPBES procedures have been in place since 2003. The goal of PPBES is to provide combatant commanders with the required resources to complete their missions. It is one part of complex series of processes that essentially

converts the U.S. National Security Strategy and President's foreign policy direction into military strategy, plans, programs, and the DoD budget. While constructed as a system, much overlap exists between the phases. For instance, planning is a nearly continuous process within DoD, and programming and budgeting are now done concurrently, in order to compress the overall timeline and allow more focus on the execution of the plan.

The purpose of the programming phase is to define programs that meet the requirements identified during planning within given fiscal constraints. The programming phase concludes with the completion of the Program Objective Memorandum (POM). This document outlines a six-year resource allocation plan. Once the POM is approved, the budgeting phase begins. Budgeteers essentially restructure the POM with more detailed numbers to conform to OMB, DoD, and service guidance for the fiscal year budget. Their finished product is called the Budget Estimate Submission (BES). DoD and OMB both review and approve the BES before inclusion into the overall President's budget (Potvin, 2009).

Congress provides funding for defense programs through authorization and appropriations acts. The annual National Defense Authorization Act establishes programs, defines responsibilities for them, sets policies, and sets conditions or limitations on activities. It authorizes the appropriation of funds, but does not actually provide money. This is provided by the annual appropriations acts, including the Defense Appropriations Act, Military Construction and Veterans Affairs Appropriations Act, and other related laws (Tyszkiewicz & Daggett, 1998). After modifications by Congress (through the appropriation and authorization acts), the President's budget forms the basis of a financial plan for each Federal agency. Budgetary resources (budget authority) are apportioned to each agency by OMB. The flow of funds to end-users includes spending restrictions to ensure congressional intent is met (Potvin, 2009).

The purpose of this brief overview is to highlight the complexities of the current budgeting process. It presents a challenge for any program, let alone an incremental upgrade to existing platforms. In addition, the POM's six-year planning horizon is not really long-term in the context of 30-year or greater platform life cycles. Convincing justifications must be made when cost savings or other benefits accrue decades after an

initial investment. This is even more important when these programs are fighting for the same scarce resources needed by current operations and maintenance requirements that many view as a higher priority. It is critically important to find a resource sponsor capable of committing funds in the out years in order to ensure continued funding for program success.

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V. CONCLUSION AND RECOMMENDATIONS

The recommendation of this BCA is to phase in implementation of shipboard LED lighting for the U.S. Navy fleet. This study found that five ship classes would experience positive life cycle cost savings given the currently assumed LED fixture price. A properly phased purchase plan could affordably outfit the fleet over 5, 10 or 20 years with LED lighting, given that the baseline's conservative assumptions hold true. A sensitivity analysis was conducted on key variables of cost and number of LED fixtures, learning curve assumption, and fuel price, and it was demonstrated in each case that reasonable predictions of the future environment make the investment case for LED lighting stronger.

Several other factors, when considered in addition to those already presented, also make the BCA more compelling. Fleet service life extensions, beyond the thirty years assumed in this study, are becoming increasingly common. For instance, the USS Enterprise, commissioned in 1961, is scheduled to remain operational through 2013. While this 52-year operational life may be an anomaly, chances are that today's newest combatants will very well see more than forty years of service, increasing the payback opportunity for cost saving innovations such as LED lighting.

High fuel and energy demands of currently fielded equipment create operational vulnerabilities for the Navy. Anything that decreases liquid fuel consumption onboard ships can increase the Navy's tactical energy security. This study has shown that LED lighting implementation can contribute to the reduction of fossil fuel requirements in the fleet. In addition, most experts agree that future mandates for the reduction of greenhouse gasses are inevitable. Since energy use is at the heart of the greenhouse gas emissions challenge, innovative energy solutions are needed to tackle both issues.

During completion of this study two additional specific findings of interest stood out:

- Be careful of self-assumptions (i.e., that a project is simply too hard or the Navy is too bureaucratic to change). The Navy's internal dialogue often

assumes that the organization is overly bureaucratic. Innovation is stifled and new ideas are not explored simply because they are considered too difficult or there is the perception that the bureaucracy will smother the initiative. In this case, however, the BCA revealed that a large investment in LED lighting technology does not make financial sense for the majority of the fleet right now. This is the most likely reason that the Navy has not fully adopted this technology.

- The Navy does not have to go "all in" at once. A partial adoption strategy makes sense and gets the Navy started down the path to greater energy efficiency. A 10 to 20 year plan to convert existing ships, starting with smaller vessels, would work just as well as the five-year plan presented in this study. Even assuming a conservative 95% learning curve, LED fixture cost reduction is dramatic. Purchase of just 1000 fixtures would drive the price below the break-even cost for the entire fleet. The important point is to get started soon and lock in multiple vendors who will supply the Navy with the specialized fixtures it demands, before they commit to the commercial industry where the Navy cannot compete on size and quantity.

APPENDIX A: FINANCIAL ANALYSIS OF FLEET CONVERSION TO LED LIGHTING

This following table provides an overview of the baseline scenario analyzed in this BCA. Key variables are highlighted on the second row (LED fixture cost, standard price of fuel, maintenance hours for fluorescent lamp change out, discount rate assumption and shipyard labor wage rate). The spreadsheet model was constructed to view the fleet-wide effects of changing these variables. The screenshot provided shows the results with baseline assumptions. The cost totals on this page are for conversion of each entire ship class. Individual ship costs are shown in Appendix D.

Variables:	LED Fixture cost	Standard Composite Fuel Cost	Maint. Hours per Fluorescent Lamp Changeout	Discount Rate	Shipyard labor cost / hour
	$1,300	$2.77	0.5	0.027	$43.75

LED Costs (95% Learning Curve)

Year	Replacement LED fixture cost
1	$1,300
6	$497
11	$473
16	$459
21	$449
26	$442

Total Navy Ships: 249

Class	FL Cost	LED Cost	Savings	Cumulative Savings	Number	% of Navy Fleet	Total Number of Fixtures	Break-even Cost per Fixture
DDG	$249,384,425	$297,502,555	-$48,118,130	-$48,118,130	55	22.1%	86,515	$1,045
SSN	$65,902,571	$112,230,812	-$46,328,241	-$94,446,371	53	21.3%	36,888	$727
FFG	$56,659,445	$44,068,883	$12,590,562	-$81,855,809	30	12.0%	11,520	$1,795
CG	$89,479,629	$72,682,385	$16,797,244	-$65,058,565	22	8.8%	19,382	$1,692
SSBN	$59,942,611	$102,081,116	-$42,138,504	-$107,197,069	18	7.2%	33,552	$727
MCM	$9,755,166	$7,999,070	$1,756,095	-$105,440,974	14	5.6%	2,142	$1,671
LSD	$86,372,017	$112,707,659	-$26,335,641	-$131,776,615	12	4.8%	35,028	$956
CVN	$187,776,233	$319,779,317	-$132,003,084	-$263,779,699	10	4.0%	95,550	$727
LPD	$105,892,835	$121,898,043	-$16,005,208	-$279,784,908	11	4.4%	36,685	$1,099
PC	$1,556,895	$1,297,766	$259,129	-$279,525,779	10	4.0%	350	$1,635
LHA/LHD	$143,499,704	$200,101,365	-$56,601,661	-$336,127,440	9	3.6%	63,135	$890
LCC/Tender	$32,918,532	$42,742,287	-$9,823,754	-$345,951,194	4	1.6%	13,268	$961
LCS	$1,963,440	$1,838,561	$124,879	-$345,826,316	1	0.4%	502	$1,411
Total:	$1,089,140,062	$1,435,091,257	-$345,951,194		249		434,517	

APPENDIX B: SHIPBOARD FIXTURE COUNT CALCULATIONS

This appendix provides an overview of fixture count calculations used in this BCA. The number of light fixtures per ship type is based on several documents provided by NAVSEA. These documents provided precise lamp counts for the LSD class and a very accurate estimation of fixtures for one CG and two DDGs currently in service. Analysis of these documents showed a wide variety of lamps and fixtures in use, and in general newer ships appeared to have more overhead fixtures for general illumination per hull volume. For instance, the DDG class had approximately 700 more overhead fixtures than the CG class, despite a lower hull displacement. These three ship classes were used as models in order to extrapolate fixture counts for the remaining 10 ship classes. Ship classes were grouped into one of three basic classifications—newer combatants, older combatants, and amphibious ships. Remaining fixture counts were calculated as a percentage of light (unloaded) displacement (in tons) of each model ship. Newer combatants use the DDG data, older combatants use the CG data and amphibious ships use the LSD data as baselines for extrapolation. The confidence level in fixture counts for LSD, CG, and DDG classes is highest, with fixture counts for the remaining classes being the best approximation available.

LIGHT FIXTURE CALCULATIONS:			
Class	Name	Light Displacement (tons)	Light Fixtures
AUX	Blue Ridge	13038	3317
	Emory S. Land	13991	3560
DDG	Arleigh Burke	6691	1573
SSN	Los Angeles	5700	696
	Seawolf	7568	924
	Virginia	5921	1392
FFG	Perry	3144	384
CG	Ticonderoga	7218	881
SSBN/SSGN	Ohio	15275	1864
MCM	Avenger	1253	153
LSD	Whidbey Island	11471	2919
	Harpers Ferry	11604	2952
CVN	Nimitz	78280	9555
	Enterprise	75704	9240
LPD	Austin	9734	2477
	San Antonio	19013	4838
LHA/LHD	Tarawa	25884	6586
	Wasp	28050	7137
LCS	Freedom	2135	502
PC	Cyclone	288	35

	Ship	Symbol 77.4 fixtures	Symbol 333.1 fixtures	Symbol 331.1 fixtures	Total	Model Average	Light Displacement
Older Combatant	CG-47	440	441	0	881	881	7218
Newer Combatant	DDG-64	1245	22	325	1592	1573	6691
	DDG-80	1239	19	295	1553		
Amphibious	LSD-41	1140	1283	161	2584	2936	11471
	LSD-49	1365	1761	161	3287		11604

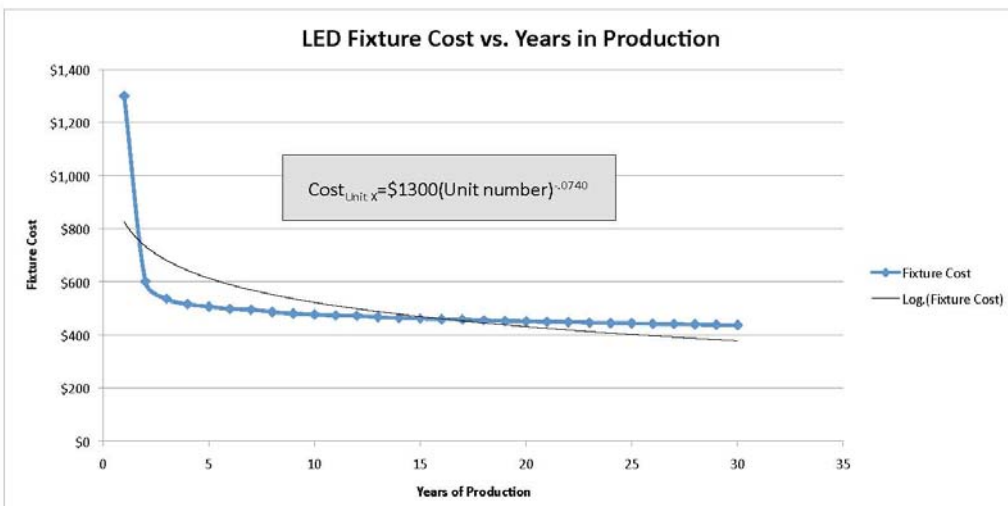
APPENDIX C: LEARNING CURVE CALCULATIONS

This appendix provides details on the learning curve assumptions used in the BCA. A 95% learning curve, typical for repetitive manufacturing of electronic components, was used in the baseline analysis. A five-year purchase sequence was assumed, with yearly lot sizes based on the total number of fixtures all classes converted in each year as outlined in Table 4.

Reduction in LED Fixture Cost with a 95% Learning Curve:

Modeled by: Cost of Unit X = (First Unit Cost) * (Unit Number)$^{-.0740}$

Year	Size	First Unit	Cum Qty	First Unit Cost	Last Unit Cost	Avg Unit Cost
1	33,896	1	33,896	$1,300	$601	$950
2	123,200	33,897	157,096	$601	$536	$569
3	111,431	157,097	268,527	$536	$515	$526
4	70,440	268,528	338,967	$515	$507	$511
5	95,550	338,968	434,517	$507	$497	$502
6	33,896	434,518	468,413	$497	$495	$496
7	123,200	468,414	591,613	$495	$486	$490
8	111,431	591,614	703,044	$486	$480	$483
9	70,440	703,045	773,484	$480	$477	$478
10	95,550	773,485	869,034	$477	$473	$475
11	33,896	869,035	902,930	$473	$471	$472
12	123,200	902,931	1,026,130	$471	$467	$469
13	111,431	1,026,131	1,137,561	$467	$463	$465
14	70,440	1,137,562	1,208,001	$463	$461	$462
15	95,550	1,208,002	1,303,551	$461	$459	$460
16	33,896	1,303,552	1,337,447	$459	$458	$458
17	123,200	1,337,448	1,460,647	$458	$455	$456
18	111,431	1,460,648	1,572,078	$455	$452	$454
19	70,440	1,572,079	1,642,518	$452	$451	$452
20	95,550	1,642,519	1,738,068	$451	$449	$450
21	33,896	1,738,069	1,771,964	$449	$448	$449
22	123,200	1,771,965	1,895,164	$448	$446	$447
23	111,431	1,895,165	2,006,595	$446	$444	$445
24	70,440	2,006,596	2,077,035	$444	$443	$444
25	95,550	2,077,036	2,172,585	$443	$442	$442
26	33,896	2,172,586	2,206,481	$442	$441	$441
27	123,200	2,206,482	2,329,681	$441	$439	$440
28	111,431	2,329,682	2,441,112	$439	$438	$439
29	70,440	2,441,113	2,511,552	$438	$437	$437
30	95,550	2,511,553	2,607,102	$437	$436	$436



APPENDIX D: BREAK-EVEN ANALYSIS BY SHIP CLASS

This appendix provides a detailed analysis of each individual ship class analyzed in the BCA. A cost comparison for a single ship in each class was conducted, to calculate the difference in life cycle costs for a fluorescent versus an LED lighting system. These totals were then multiplied by the total number of ships in each class to analyze cost savings resulting from conversion of an entire class to LED lighting.

Arleigh Burke Class DDG

Propulsion:	Gas Turbine
Number in Service:	55
Displacement (Light Tons):	6691
Number of Fixtures:	1573
Number of Lamps:	2856
Fuel Burden Factor:	1
Generator GPH:	147.2

COST COMPARISON FOR ENTIRE CLASS:	
Lifecycle Cost of Status Quo:	$249,384,425.26
Lifecycle Cost with LEDs:	$297,502,555.24
Lifecycle Cost Savings:	-$48,118,129.98

COST COMPARISON FOR ONE VESSEL:

	Fluorescent Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	-	-	-	-	-	-	-
1	$0	$99,846	$122,323	$286	$222,455	1.0270	$216,606
2	$0	$99,846	$122,323	$286	$222,455	1.0547	$210,912
3	$0	$99,846	$122,323	$286	$222,455	1.0832	$205,367
4	$0	$99,846	$122,323	$286	$222,455	1.1125	$199,968
5	$0	$99,846	$122,323	$286	$222,455	1.1425	$194,710
6	$0	$99,846	$122,323	$286	$222,455	1.1733	$189,591
7	$0	$99,846	$122,323	$286	$222,455	1.2050	$184,607
8	$0	$99,846	$122,323	$286	$222,455	1.2376	$179,754
9	$0	$99,846	$122,323	$286	$222,455	1.2710	$175,028
10	$0	$99,846	$122,323	$286	$222,455	1.3053	$170,426
11	$0	$99,846	$122,323	$286	$222,455	1.3405	$165,946
12	$0	$99,846	$122,323	$286	$222,455	1.3767	$161,583
13	$0	$99,846	$122,323	$286	$222,455	1.4139	$157,335
14	$0	$99,846	$122,323	$286	$222,455	1.4521	$153,199
15	$0	$99,846	$122,323	$286	$222,455	1.4913	$149,171
16	$0	$99,846	$122,323	$286	$222,455	1.5315	$145,249
17	$0	$99,846	$122,323	$286	$222,455	1.5729	$141,431
18	$0	$99,846	$122,323	$286	$222,455	1.6154	$137,712
19	$0	$99,846	$122,323	$286	$222,455	1.6590	$134,092
20	$0	$99,846	$122,323	$286	$222,455	1.7038	$130,567
21	$0	$99,846	$122,323	$286	$222,455	1.7498	$127,134
22	$0	$99,846	$122,323	$286	$222,455	1.7970	$123,792
23	$0	$99,846	$122,323	$286	$222,455	1.8455	$120,537
24	$0	$99,846	$122,323	$286	$222,455	1.8954	$117,368
25	$0	$99,846	$122,323	$286	$222,455	1.9465	$114,283
26	$0	$99,846	$122,323	$286	$222,455	1.9991	$111,278
27	$0	$99,846	$122,323	$286	$222,455	2.0531	$108,353
28	$0	$99,846	$122,323	$286	$222,455	2.1085	$105,504
29	$0	$99,846	$122,323	$286	$222,455	2.1654	$102,730
30	$0	$99,846	$122,323	$286	$222,455	2.2239	$100,029
Total:	$0	$2,995,373	$3,669,696	$8,568	$6,673,637		
				NPV:	$4,534,262		$4,534,262

	LED Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	$2,113,718.75	-	-	-	$2,113,718.75	1.0000	$2,113,718.75
1	$0	$0	$30,581	$0	$30,581	1.0270	$29,776.83
2	$0	$0	$30,581	$0	$30,581	1.0547	$28,993.99
3	$0	$0	$30,581	$0	$30,581	1.0832	$28,231.73
4	$0	$0	$30,581	$0	$30,581	1.1125	$27,489.51
5	$0	$0	$30,581	$0	$30,581	1.1425	$26,766.81
6	$851,274	$0	$30,581	$0	$881,855	1.1733	$751,578.61
7	$0	$0	$30,581	$0	$30,581	1.2050	$25,377.90
8	$0	$0	$30,581	$0	$30,581	1.2376	$24,710.71
9	$0	$0	$30,581	$0	$30,581	1.2710	$24,061.07
10	$0	$0	$30,581	$0	$30,581	1.3053	$23,428.50
11	$812,152	$0	$30,581	$0	$842,732	1.3405	$628,658.52
12	$0	$0	$30,581	$0	$30,581	1.3767	$22,212.81
13	$0	$0	$30,581	$0	$30,581	1.4139	$21,628.83
14	$0	$0	$30,581	$0	$30,581	1.4521	$21,060.21
15	$0	$0	$30,581	$0	$30,581	1.4913	$20,506.53
16	$790,180	$0	$30,581	$0	$820,760	1.5315	$535,906.84
17	$0	$0	$30,581	$0	$30,581	1.5729	$19,442.46
18	$0	$0	$30,581	$0	$30,581	1.6154	$18,931.32
19	$0	$0	$30,581	$0	$30,581	1.6590	$18,433.61
20	$0	$0	$30,581	$0	$30,581	1.7038	$17,948.99
21	$774,985	$0	$30,581	$0	$805,566	1.7498	$460,385.72
22	$0	$0	$30,581	$0	$30,581	1.7970	$17,017.63
23	$0	$0	$30,581	$0	$30,581	1.8455	$16,570.23
24	$0	$0	$30,581	$0	$30,581	1.8954	$16,134.60
25	$0	$0	$30,581	$0	$30,581	1.9465	$15,710.42
26	$763,420	$0	$30,581	$0	$794,001	1.9991	$397,182.04
27	$0	$0	$30,581	$0	$30,581	2.0531	$14,895.22
28	$0	$0	$30,581	$0	$30,581	2.1085	$14,503.62
29	$0	$0	$30,581	$0	$30,581	2.1654	$14,122.32
30	$0	$0	$30,581	$0	$30,581	2.2239	$13,751.04
Total:	$6,105,730	$0	$917,424	$0	$7,023,154		
				NPV:	$5,409,137		$5,409,137

Cost Formulas:

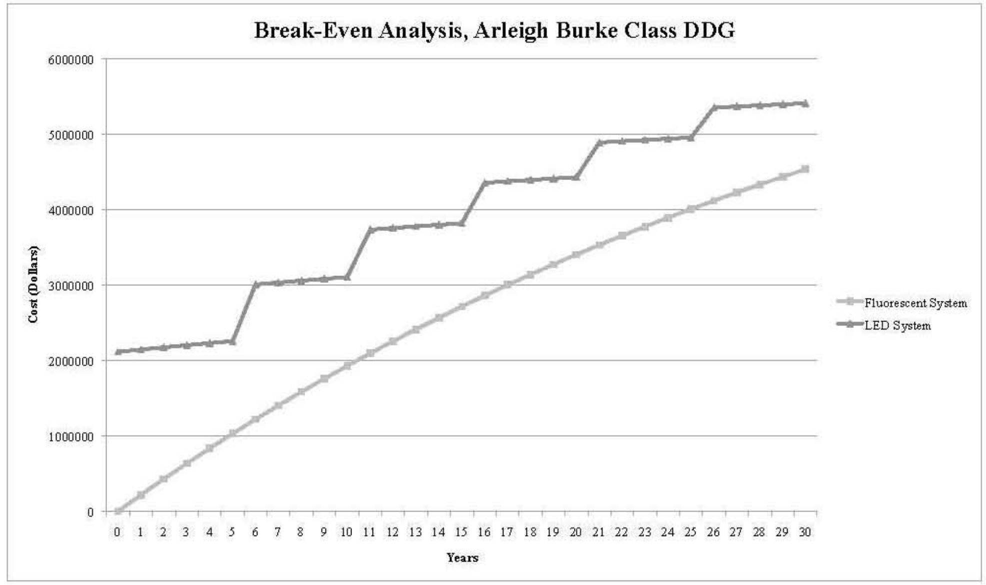
Investment: (fixtures)*(Cost per fixture)+(fixtures)*(hours to install)*(labor cost/hour)

Maintenance: (lamps replaced)*(time to replace)*(labor cost/hour)*(# of personnel)+(lamps replaced)*(cost per lamp)+(ballasts replaced)*(cost per ballast)+(starters replaced)*(cost per starter)

Operation: (gallons/hour)*(price per gallon)*(fuel burden factor)*(20 hours/day)*(days underway per year)*(number of generators-1)*5%

Disposal: (failed lamps)*(feet per lamp)*(recycle cost)

Year	FL cost, Cum PV	LED cost, Cum PV	Cum Cost Savings
0	0	$2,113,719	-$2,113,719
1	$216,606	$2,143,496	-$1,926,889
2	$427,518	$2,172,490	-$1,744,972
3	$632,884	$2,200,721	-$1,567,837
4	$832,852	$2,228,211	-$1,395,359
5	$1,027,562	$2,254,978	-$1,227,415
6	$1,217,154	$3,006,556	-$1,789,402
7	$1,401,761	$3,031,934	-$1,630,173
8	$1,581,514	$3,056,645	-$1,475,130
9	$1,756,542	$3,080,706	-$1,324,164
10	$1,926,969	$3,104,134	-$1,177,166
11	$2,092,915	$3,732,793	-$1,639,878
12	$2,254,498	$3,755,006	-$1,500,508
13	$2,411,833	$3,776,635	-$1,364,802
14	$2,565,032	$3,797,695	-$1,232,663
15	$2,714,203	$3,818,201	-$1,103,999
16	$2,859,452	$4,354,108	-$1,494,656
17	$3,000,883	$4,373,551	-$1,372,668
18	$3,138,595	$4,392,482	-$1,253,887
19	$3,272,687	$4,410,916	-$1,138,228
20	$3,403,254	$4,428,865	-$1,025,611
21	$3,530,388	$4,889,250	-$1,358,862
22	$3,654,180	$4,906,268	-$1,252,088
23	$3,774,717	$4,922,838	-$1,148,121
24	$3,892,085	$4,938,973	-$1,046,888
25	$4,006,368	$4,954,683	-$948,315
26	$4,117,646	$5,351,865	-$1,234,219
27	$4,225,999	$5,366,760	-$1,140,762
28	$4,331,503	$5,381,264	-$1,049,761
29	$4,434,233	$5,395,386	-$961,154
30	$4,534,262	$5,409,137	-$874,875



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$6,105,730	$0	$917,424	$0	$7,023,154	*$5,409,137*
Fluorescent	$0	$2,995,373	$3,669,696	$8,568	$6,673,637	*$4,534,262*

Assumptions:	Number of fixtures	Fixture cost	Fuel cost	Maint. Hours	Discount Rate	Shipyard labor cost / hour
	1573	$1,300.00	$1.00	0.5	0.027	$43.75

Ticonderoga Class CG

Propulsion:	Gas Turbine
Number in Service:	22
Displacement (Light Tons):	7218
Number of Fixtures:	881
Number of Lamps:	2203
Fuel Burden Factor:	1
Generator GPH:	147.2

COST COMPARISON FOR ENTIRE CLASS:	
Lifecycle Cost of Status Quo:	$89,479,629.39
Lifecycle Cost with LEDs:	$72,682,385.25
Lifecycle Cost Savings:	$16,797,244.14

COST COMPARISON FOR ONE VESSEL:

Fluorescent Lighting System

Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	-	-	-	-	-	-	-
1	$0	$76,999	$122,323	$220	$199,543	1.0270	$194,297
2	$0	$76,999	$122,323	$220	$199,543	1.0547	$189,189
3	$0	$76,999	$122,323	$220	$199,543	1.0832	$184,215
4	$0	$76,999	$122,323	$220	$199,543	1.1125	$179,372
5	$0	$76,999	$122,323	$220	$199,543	1.1425	$174,656
6	$0	$76,999	$122,323	$220	$199,543	1.1733	$170,064
7	$0	$76,999	$122,323	$220	$199,543	1.2050	$165,593
8	$0	$76,999	$122,323	$220	$199,543	1.2376	$161,240
9	$0	$76,999	$122,323	$220	$199,543	1.2710	$157,001
10	$0	$76,999	$122,323	$220	$199,543	1.3053	$152,873
11	$0	$76,999	$122,323	$220	$199,543	1.3405	$148,854
12	$0	$76,999	$122,323	$220	$199,543	1.3767	$144,941
13	$0	$76,999	$122,323	$220	$199,543	1.4139	$141,130
14	$0	$76,999	$122,323	$220	$199,543	1.4521	$137,420
15	$0	$76,999	$122,323	$220	$199,543	1.4913	$133,807
16	$0	$76,999	$122,323	$220	$199,543	1.5315	$130,289
17	$0	$76,999	$122,323	$220	$199,543	1.5729	$126,864
18	$0	$76,999	$122,323	$220	$199,543	1.6154	$123,529
19	$0	$76,999	$122,323	$220	$199,543	1.6590	$120,281
20	$0	$76,999	$122,323	$220	$199,543	1.7038	$117,119
21	$0	$76,999	$122,323	$220	$199,543	1.7498	$114,040
22	$0	$76,999	$122,323	$220	$199,543	1.7970	$111,042
23	$0	$76,999	$122,323	$220	$199,543	1.8455	$108,122
24	$0	$76,999	$122,323	$220	$199,543	1.8954	$105,280
25	$0	$76,999	$122,323	$220	$199,543	1.9465	$102,512
26	$0	$76,999	$122,323	$220	$199,543	1.9991	$99,817
27	$0	$76,999	$122,323	$220	$199,543	2.0531	$97,193
28	$0	$76,999	$122,323	$220	$199,543	2.1085	$94,638
29	$0	$76,999	$122,323	$220	$199,543	2.1654	$92,150
30	$0	$76,999	$122,323	$220	$199,543	2.2239	$89,727
Total:	$0	$2,309,982	$3,669,696	$6,608	$5,986,286		
				NPV:	$4,067,256		$4,067,256

LED Lighting System

Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	$1,183,844	-	-	-	$1,183,844	1.0000	$1,183,844
1	$0	$0	$30,581	$0	$30,581	1.0270	$29,777
2	$0	$0	$30,581	$0	$30,581	1.0547	$28,994
3	$0	$0	$30,581	$0	$30,581	1.0832	$28,232
4	$0	$0	$30,581	$0	$30,581	1.1125	$27,490
5	$0	$0	$30,581	$0	$30,581	1.1425	$26,767
6	$476,778	$0	$30,581	$0	$507,359	1.1733	$432,407
7	$0	$0	$30,581	$0	$30,581	1.2050	$25,378
8	$0	$0	$30,581	$0	$30,581	1.2376	$24,711
9	$0	$0	$30,581	$0	$30,581	1.2710	$24,061
10	$0	$0	$30,581	$0	$30,581	1.3053	$23,428
11	$454,867	$0	$30,581	$0	$485,448	1.3405	$362,133
12	$0	$0	$30,581	$0	$30,581	1.3767	$22,213
13	$0	$0	$30,581	$0	$30,581	1.4139	$21,629
14	$0	$0	$30,581	$0	$30,581	1.4521	$21,060
15	$0	$0	$30,581	$0	$30,581	1.4913	$20,507
16	$442,561	$0	$30,581	$0	$473,142	1.5315	$308,933
17	$0	$0	$30,581	$0	$30,581	1.5729	$19,442
18	$0	$0	$30,581	$0	$30,581	1.6154	$18,931
19	$0	$0	$30,581	$0	$30,581	1.6590	$18,434
20	$0	$0	$30,581	$0	$30,581	1.7038	$17,949
21	$434,051	$0	$30,581	$0	$464,632	1.7498	$265,540
22	$0	$0	$30,581	$0	$30,581	1.7970	$17,018
23	$0	$0	$30,581	$0	$30,581	1.8455	$16,570
24	$0	$0	$30,581	$0	$30,581	1.8954	$16,135
25	$0	$0	$30,581	$0	$30,581	1.9465	$15,710
26	$427,574	$0	$30,581	$0	$458,154	1.9991	$229,182
27	$0	$0	$30,581	$0	$30,581	2.0531	$14,895
28	$0	$0	$30,581	$0	$30,581	2.1085	$14,504
29	$0	$0	$30,581	$0	$30,581	2.1654	$14,122
30	$0	$0	$30,581	$0	$30,581	2.2239	$13,751
Total:	$3,419,674	$0	$917,424	$0	$4,337,098		
				NPV:	$3,303,745		$3,303,745

Cost Formulas:

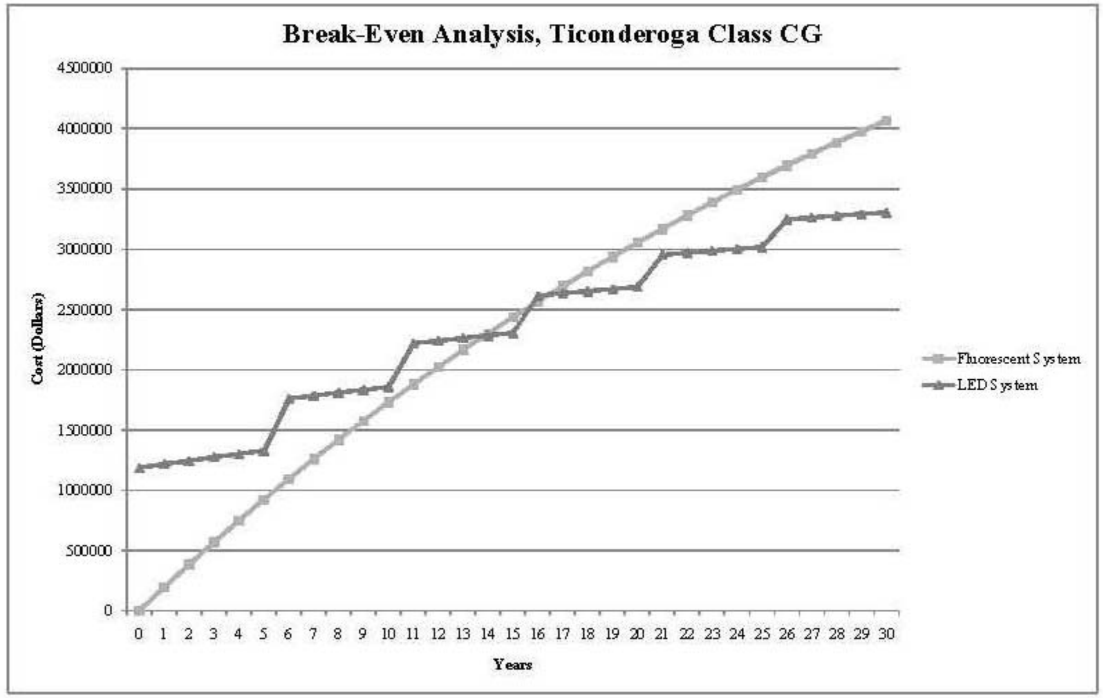
Investment: (fixtures)*(Cost per fixture)+(fixtures)*(hours to install)*(labor cost/hour)

Maintenance: (lamps replaced)*(time to replace)*(labor cost/hour)*(# of personnel)+(lamps replaced)*(cost per lamp)+(ballasts replaced)*(cost per ballast)+(starters replaced)*(cost per starter)

Operation: [(sfc*power in watts*time in hours)/8.33*746]*(price per gallon)*(days underway per year)

Disposal: (failed lamps)*(feet per lamp)*(recycle cost)

Year	FL cost, Cum PV	LED cost, Cum PV	Cum Cost Savings
0	0	$1,183,844	-$1,183,844
1	$194,297	$1,213,621	-$1,019,324
2	$383,486	$1,242,615	-$859,129
3	$567,701	$1,270,846	-$703,146
4	$747,072	$1,298,336	-$551,263
5	$921,729	$1,325,103	-$403,374
6	$1,091,793	$1,757,510	-$665,717
7	$1,257,386	$1,782,888	-$525,501
8	$1,418,626	$1,807,598	-$388,972
9	$1,575,627	$1,831,659	-$256,032
10	$1,728,501	$1,855,088	-$126,587
11	$1,877,355	$2,217,220	-$339,866
12	$2,022,296	$2,239,433	-$217,138
13	$2,163,426	$2,261,062	-$97,636
14	$2,300,846	$2,282,122	$18,724
15	$2,434,653	$2,302,629	$132,024
16	$2,564,943	$2,611,562	-$46,619
17	$2,691,807	$2,631,004	$60,803
18	$2,815,336	$2,649,935	$165,400
19	$2,935,617	$2,668,369	$267,248
20	$3,052,736	$2,686,318	$366,418
21	$3,166,776	$2,951,858	$214,918
22	$3,277,817	$2,968,875	$308,942
23	$3,385,940	$2,985,446	$400,494
24	$3,491,220	$3,001,580	$489,640
25	$3,593,732	$3,017,291	$576,441
26	$3,693,549	$3,246,473	$447,076
27	$3,790,742	$3,261,368	$529,374
28	$3,885,379	$3,275,871	$609,508
29	$3,977,529	$3,289,994	$687,535
30	$4,067,256	$3,303,745	$763,511



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$3,419,674	$0	$917,424	$0	$4,337,098	$3,303,745
Fluorescent	$0	$2,309,982	$3,669,696	$6,608	$5,986,286	$4,067,256

Assumptions:	Number of fixtures	Fixture cost	Fuel cost	Maint. Hours	Discount Rate	Shipyard labor cost / hour
	881	$1,300.00	$2.77	0.5	0.027	$43.75

Oliver Hazard Perry Class FFG

Propulsion:	Gas Turbine
Number in Service:	30
Displacement (Light Tons):	3144
Number of Fixtures:	384
Number of Lamps:	960
Fuel Burden Factor:	1
Generator GPH:	71

COST COMPARISON FOR ENTIRE CLASS:	
Lifecycle Cost of Status Quo:	$56,659,444.70
Lifecycle Cost with LEDs:	$44,068,882.71
Lifecycle Cost Savings:	$12,590,561.98

COST COMPARISON FOR ONE VESSEL:

	Fluorescent Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	-	-	-	-	-	-	-
1	$0	$33,562	$59,001	$96	$92,659	1.0270	$90,223
2	$0	$33,562	$59,001	$96	$92,659	1.0547	$87,851
3	$0	$33,562	$59,001	$96	$92,659	1.0832	$85,541
4	$0	$33,562	$59,001	$96	$92,659	1.1125	$83,292
5	$0	$33,562	$59,001	$96	$92,659	1.1425	$81,102
6	$0	$33,562	$59,001	$96	$92,659	1.1733	$78,970
7	$0	$33,562	$59,001	$96	$92,659	1.2050	$76,894
8	$0	$33,562	$59,001	$96	$92,659	1.2376	$74,872
9	$0	$33,562	$59,001	$96	$92,659	1.2710	$72,904
10	$0	$33,562	$59,001	$96	$92,659	1.3053	$70,987
11	$0	$33,562	$59,001	$96	$92,659	1.3405	$69,121
12	$0	$33,562	$59,001	$96	$92,659	1.3767	$67,304
13	$0	$33,562	$59,001	$96	$92,659	1.4139	$65,534
14	$0	$33,562	$59,001	$96	$92,659	1.4521	$63,812
15	$0	$33,562	$59,001	$96	$92,659	1.4913	$62,134
16	$0	$33,562	$59,001	$96	$92,659	1.5315	$60,500
17	$0	$33,562	$59,001	$96	$92,659	1.5729	$58,910
18	$0	$33,562	$59,001	$96	$92,659	1.6154	$57,361
19	$0	$33,562	$59,001	$96	$92,659	1.6590	$55,853
20	$0	$33,562	$59,001	$96	$92,659	1.7038	$54,385
21	$0	$33,562	$59,001	$96	$92,659	1.7498	$52,955
22	$0	$33,562	$59,001	$96	$92,659	1.7970	$51,563
23	$0	$33,562	$59,001	$96	$92,659	1.8455	$50,207
24	$0	$33,562	$59,001	$96	$92,659	1.8954	$48,887
25	$0	$33,562	$59,001	$96	$92,659	1.9465	$47,602
26	$0	$33,562	$59,001	$96	$92,659	1.9991	$46,350
27	$0	$33,562	$59,001	$96	$92,659	2.0531	$45,132
28	$0	$33,562	$59,001	$96	$92,659	2.1085	$43,945
29	$0	$33,562	$59,001	$96	$92,659	2.1654	$42,790
30	$0	$33,562	$59,001	$96	$92,659	2.2239	$41,665
Total:	$0	$1,006,848	$1,770,030	$2,880	$2,779,758		
				NPV:	$1,888,648		$1,888,648

	LED Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	$516,000	-	-	-	$516,000	1.0000	$516,000
1	$0	$0	$14,750	$0	$14,750	1.0270	$14,362
2	$0	$0	$14,750	$0	$14,750	1.0547	$13,985
3	$0	$0	$14,750	$0	$14,750	1.0832	$13,617
4	$0	$0	$14,750	$0	$14,750	1.1125	$13,259
5	$0	$0	$14,750	$0	$14,750	1.1425	$12,911
6	$207,813	$0	$14,750	$0	$222,563	1.1733	$189,684
7	$0	$0	$14,750	$0	$14,750	1.2050	$12,241
8	$0	$0	$14,750	$0	$14,750	1.2376	$11,919
9	$0	$0	$14,750	$0	$14,750	1.2710	$11,606
10	$0	$0	$14,750	$0	$14,750	1.3053	$11,300
11	$198,262	$0	$14,750	$0	$213,012	1.3405	$158,902
12	$0	$0	$14,750	$0	$14,750	1.3767	$10,714
13	$0	$0	$14,750	$0	$14,750	1.4139	$10,432
14	$0	$0	$14,750	$0	$14,750	1.4521	$10,158
15	$0	$0	$14,750	$0	$14,750	1.4913	$9,891
16	$192,898	$0	$14,750	$0	$207,649	1.5315	$135,582
17	$0	$0	$14,750	$0	$14,750	1.5729	$9,378
18	$0	$0	$14,750	$0	$14,750	1.6154	$9,131
19	$0	$0	$14,750	$0	$14,750	1.6590	$8,891
20	$0	$0	$14,750	$0	$14,750	1.7038	$8,657
21	$189,189	$0	$14,750	$0	$203,939	1.7498	$116,552
22	$0	$0	$14,750	$0	$14,750	1.7970	$8,208
23	$0	$0	$14,750	$0	$14,750	1.8455	$7,992
24	$0	$0	$14,750	$0	$14,750	1.8954	$7,782
25	$0	$0	$14,750	$0	$14,750	1.9465	$7,578
26	$186,366	$0	$14,750	$0	$201,116	1.9991	$100,604
27	$0	$0	$14,750	$0	$14,750	2.0531	$7,185
28	$0	$0	$14,750	$0	$14,750	2.1085	$6,996
29	$0	$0	$14,750	$0	$14,750	2.1654	$6,812
30	$0	$0	$14,750	$0	$14,750	2.2239	$6,633
Total:	$1,490,528	$0	$442,508	$0	$1,933,035		
				NPV:	$1,468,963		$1,468,963

Cost Formulas:

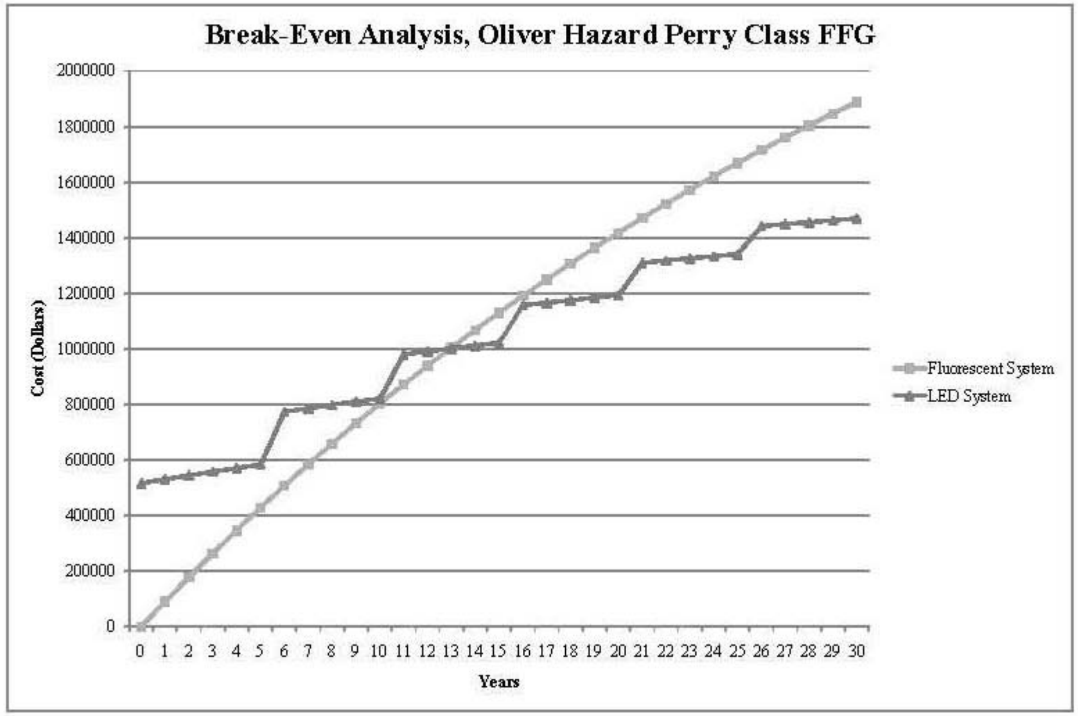
Investment: (fixtures)*(Cost per fixture)+(fixtures)*(hours to install)*(labor cost/hour)

Maintenance: (lamps replaced)*(time to replace)*(labor cost/hour)*(# of personnel)+(lamps replaced)*(cost per lamp)+(ballasts replaced)*(cost per ballast)+(starters replaced)*(cost per starter)

Operation: (gallons/hour)*(price per gallon)*(fuel burden factor)*(20 hours/day)*(days underway per year)*(number of generators-1)*5%

Disposal: (failed lamps)*(feet per lamp)*(recycle cost)

Year	FL cost, Cum PV	LED cost, Cum PV	Cum Cost Savings
0	0	$516,000	-$516,000
1	$90,223	$530,362	-$440,140
2	$178,073	$544,347	-$366,274
3	$263,614	$557,965	-$294,350
4	$346,906	$571,224	-$224,317
5	$428,009	$584,134	-$156,126
6	$506,979	$773,818	-$266,839
7	$583,873	$786,059	-$202,186
8	$658,745	$797,978	-$139,232
9	$731,649	$809,583	-$77,934
10	$802,637	$820,884	-$18,247
11	$871,758	$979,786	-$108,028
12	$939,062	$990,500	-$51,438
13	$1,004,596	$1,000,932	$3,664
14	$1,068,408	$1,011,090	$57,318
15	$1,130,542	$1,020,981	$109,561
16	$1,191,042	$1,156,563	$34,479
17	$1,249,952	$1,165,941	$84,011
18	$1,307,313	$1,175,072	$132,241
19	$1,363,167	$1,183,964	$179,203
20	$1,417,551	$1,192,621	$224,930
21	$1,470,506	$1,309,174	$161,333
22	$1,522,069	$1,317,382	$204,687
23	$1,572,276	$1,325,374	$246,902
24	$1,621,163	$1,333,157	$288,007
25	$1,668,765	$1,340,734	$328,031
26	$1,715,116	$1,441,338	$273,777
27	$1,760,248	$1,448,523	$311,725
28	$1,804,193	$1,455,518	$348,675
29	$1,846,983	$1,462,330	$384,653
30	$1,888,648	$1,468,963	$419,685



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$1,490,528	$0	$442,508	$0	$1,933,035	*$1,468,963*
Fluorescent	$0	$1,006,848	$1,770,030	$2,880	$2,779,758	*$1,888,648*

Assumptions:	Number of fixtures	Fixture cost	Fuel cost	Maint. Hours	Discount Rate	Shipyard labor cost / hour
	384	$1,300.00	$2.77	0.5	0.027	$43.75

CVN

	Nimitz	Enterprise
Propulsion:	Nuclear	Nuclear
Number in Service:	10	1
Displacement (Light Tons):	78280	75704
Number of Fixtures:	9555	9240
Number of Lamps:	23888	23100
Fuel Burden Factor:	0	0
Generator GPH:	n/a	n/a

COST COMPARISON FOR ENTIRE CLASS:	
Lifecycle Cost of Status Quo:	$187,776,232.84
Lifecycle Cost with LEDs:	$319,779,317.23
Lifecycle Cost Savings:	-$132,003,084.39

COST COMPARISON FOR ONE VESSEL:

	Fluorescent Lighting System							LED Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	-	-	-	-	-	-	-	$12,839,531	-	-	-	$12,839,531	1.0000	$12,839,531
1	$0	$835,107	$0	$2,389	$837,496	1.0270	$815,478	$0	$0	$0	$0	$0	1.0270	$0
2	$0	$835,107	$0	$2,389	$837,496	1.0547	$794,039	$0	$0	$0	$0	$0	1.0547	$0
3	$0	$835,107	$0	$2,389	$837,496	1.0832	$773,163	$0	$0	$0	$0	$0	1.0832	$0
4	$0	$835,107	$0	$2,389	$837,496	1.1125	$752,837	$0	$0	$0	$0	$0	1.1125	$0
5	$0	$835,107	$0	$2,389	$837,496	1.1425	$733,045	$0	$0	$0	$0	$0	1.1425	$0
6	$0	$835,107	$0	$2,389	$837,496	1.1733	$713,773	$5,170,962	$0	$0	$0	$5,170,962	1.1733	$4,407,057
7	$0	$835,107	$0	$2,389	$837,496	1.2050	$695,008	$0	$0	$0	$0	$0	1.2050	$0
8	$0	$835,107	$0	$2,389	$837,496	1.2376	$676,736	$0	$0	$0	$0	$0	1.2376	$0
9	$0	$835,107	$0	$2,389	$837,496	1.2710	$658,944	$0	$0	$0	$0	$0	1.2710	$0
10	$0	$835,107	$0	$2,389	$837,496	1.3053	$641,620	$0	$0	$0	$0	$0	1.3053	$0
11	$0	$835,107	$0	$2,389	$837,496	1.3405	$624,752	$4,933,317	$0	$0	$0	$4,933,317	1.3405	$3,680,139
12	$0	$835,107	$0	$2,389	$837,496	1.3767	$608,327	$0	$0	$0	$0	$0	1.3767	$0
13	$0	$835,107	$0	$2,389	$837,496	1.4139	$592,334	$0	$0	$0	$0	$0	1.4139	$0
14	$0	$835,107	$0	$2,389	$837,496	1.4521	$576,762	$0	$0	$0	$0	$0	1.4521	$0
15	$0	$835,107	$0	$2,389	$837,496	1.4913	$561,599	$0	$0	$0	$0	$0	1.4913	$0
16	$0	$835,107	$0	$2,389	$837,496	1.5315	$546,834	$4,799,851	$0	$0	$0	$4,799,851	1.5315	$3,134,012
17	$0	$835,107	$0	$2,389	$837,496	1.5729	$532,458	$0	$0	$0	$0	$0	1.5729	$0
18	$0	$835,107	$0	$2,389	$837,496	1.6154	$518,459	$0	$0	$0	$0	$0	1.6154	$0
19	$0	$835,107	$0	$2,389	$837,496	1.6590	$504,829	$0	$0	$0	$0	$0	1.6590	$0
20	$0	$835,107	$0	$2,389	$837,496	1.7038	$491,557	$0	$0	$0	$0	$0	1.7038	$0
21	$0	$835,107	$0	$2,389	$837,496	1.7498	$478,634	$4,707,555	$0	$0	$0	$4,707,555	1.7498	$2,690,395
22	$0	$835,107	$0	$2,389	$837,496	1.7970	$466,050	$0	$0	$0	$0	$0	1.7970	$0
23	$0	$835,107	$0	$2,389	$837,496	1.8455	$453,798	$0	$0	$0	$0	$0	1.8455	$0
24	$0	$835,107	$0	$2,389	$837,496	1.8954	$441,867	$0	$0	$0	$0	$0	1.8954	$0
25	$0	$835,107	$0	$2,389	$837,496	1.9465	$430,251	$0	$0	$0	$0	$0	1.9465	$0
26	$0	$835,107	$0	$2,389	$837,496	1.9991	$418,939	$4,637,305	$0	$0	$0	$4,637,305	1.9991	$2,319,713
27	$0	$835,107	$0	$2,389	$837,496	2.0531	$407,925	$0	$0	$0	$0	$0	2.0531	$0
28	$0	$835,107	$0	$2,389	$837,496	2.1085	$397,201	$0	$0	$0	$0	$0	2.1085	$0
29	$0	$835,107	$0	$2,389	$837,496	2.1654	$386,758	$0	$0	$0	$0	$0	2.1654	$0
30	$0	$835,107	$0	$2,389	$837,496	2.2239	$376,590	$0	$0	$0	$0	$0	2.2239	$0
Total:	$0	$25,053,210	$0	$71,663	$25,124,873			$37,088,522	$0	$0	$0	$37,088,522		
				NPV:	$17,070,567		$17,070,567				NPV:	$29,070,847		$29,070,847

Cost Formulas:

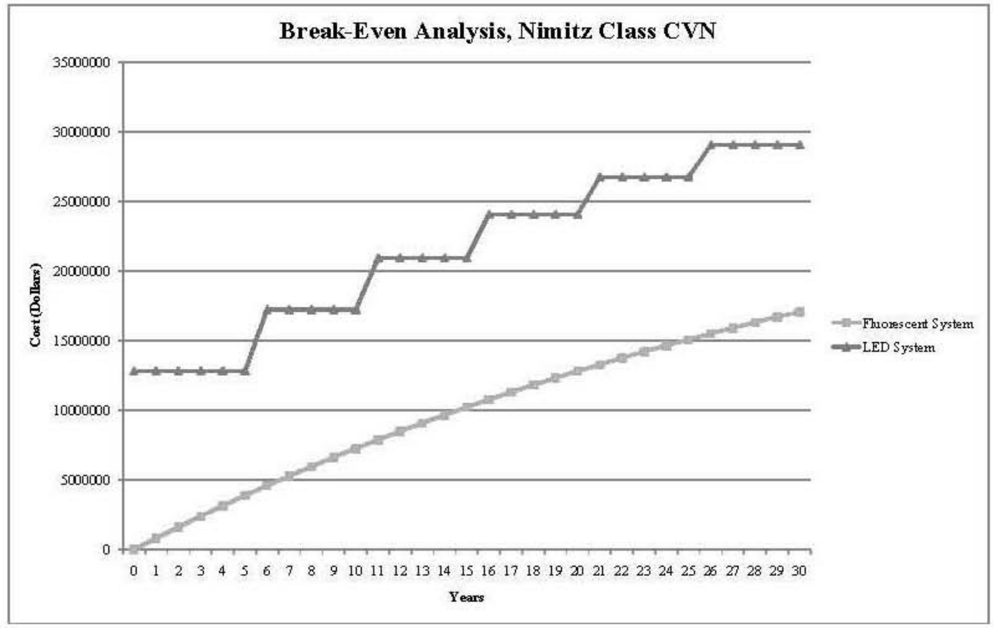
Investment: (fixtures)*(Cost per fixture)+(fixtures)*(hours to install)*(labor cost/hour)

Maintenance: (lamps replaced)*(time to replace)*(labor cost/hour)*(# of personnel)+(lamps replaced)*(cost per lamp)+(ballasts replaced)*(cost per ballast)+(starters replaced)*(cost per starter)

Operation: [(sfc*power in watts*time in hours)/8.33*746]*(price per gallon)*(days underway per year)

Disposal: (failed lamps)*(feet per lamp)*(recycle cost)

Year	FL cost, Cum PV	LED cost, Cum PV	Cum Cost Savings
0	0	$12,839,531	-$12,839,531
1	$815,478	$12,839,531	-$12,024,053
2	$1,609,517	$12,839,531	-$11,230,015
3	$2,382,680	$12,839,531	-$10,456,851
4	$3,135,517	$12,839,531	-$9,704,014
5	$3,868,561	$12,839,531	-$8,970,970
6	$4,582,334	$17,246,588	-$12,664,254
7	$5,277,342	$17,246,588	-$11,969,247
8	$5,954,077	$17,246,588	-$11,292,511
9	$6,613,022	$17,246,588	-$10,633,567
10	$7,254,642	$17,246,588	-$9,991,946
11	$7,879,394	$20,926,727	-$13,047,333
12	$8,487,721	$20,926,727	-$12,439,006
13	$9,080,056	$20,926,727	-$11,846,671
14	$9,656,817	$20,926,727	-$11,269,910
15	$10,218,416	$20,926,727	-$10,708,311
16	$10,765,250	$24,060,739	-$13,295,489
17	$11,297,707	$24,060,739	-$12,763,032
18	$11,816,167	$24,060,739	-$12,244,573
19	$12,320,996	$24,060,739	-$11,739,744
20	$12,812,552	$24,060,739	-$11,248,187
21	$13,291,186	$26,751,134	-$13,459,948
22	$13,757,236	$26,751,134	-$12,993,898
23	$14,211,034	$26,751,134	-$12,540,100
24	$14,652,902	$26,751,134	-$12,098,233
25	$15,083,152	$26,751,134	-$11,667,982
26	$15,502,092	$29,070,847	-$13,568,755
27	$15,910,017	$29,070,847	-$13,160,830
28	$16,307,218	$29,070,847	-$12,763,629
29	$16,693,976	$29,070,847	-$12,376,871
30	$17,070,567	$29,070,847	-$12,000,280



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$37,088,522	$0	$0	$0	$37,088,522	***$29,070,847***
Fluorescent	$0	$25,053,210	$0	$71,663	$25,124,873	*$17,070,567*

Assumptions:	Number of fixtures	Fixture cost	Fuel cost	Maint. Hours	Discount Rate	Shipyard labor cost / hour
	9555	$1,300.00	$2.77	0.5	0.027	$43.75

SSN

	Los Angeles	Seawolf	Virginia
Propulsion:	Nuclear	Nuclear	Nuclear
Number in Service:	45	3	5
Displacement (Light Tons):	5700	7568	5921
Number of Fixtures:	696	924	1121
Number of Lamps:	1740	2310	2018
Fuel Burden Factor:	0	0	0
Generator GPH:	n/a	n/a	n/a

COST COMPARISON FOR ENTIRE CLASS:	
Lifecycle Cost of Status Quo:	$65,902,570.54
Lifecycle Cost with LEDs:	$112,230,811.61
Lifecycle Cost Savings:	-$46,328,241.06

COST COMPARISON FOR ONE VESSEL:

Fluorescent Lighting System

Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	-	-	-	-	-	-	-
1	$0	$60,830	$0	$174	$61,004	1.0270	$59,401
2	$0	$60,830	$0	$174	$61,004	1.0547	$57,839
3	$0	$60,830	$0	$174	$61,004	1.0832	$56,318
4	$0	$60,830	$0	$174	$61,004	1.1125	$54,838
5	$0	$60,830	$0	$174	$61,004	1.1425	$53,396
6	$0	$60,830	$0	$174	$61,004	1.1733	$51,992
7	$0	$60,830	$0	$174	$61,004	1.2050	$50,625
8	$0	$60,830	$0	$174	$61,004	1.2376	$49,294
9	$0	$60,830	$0	$174	$61,004	1.2710	$47,998
10	$0	$60,830	$0	$174	$61,004	1.3053	$46,737
11	$0	$60,830	$0	$174	$61,004	1.3405	$45,508
12	$0	$60,830	$0	$174	$61,004	1.3767	$44,311
13	$0	$60,830	$0	$174	$61,004	1.4139	$43,146
14	$0	$60,830	$0	$174	$61,004	1.4521	$42,012
15	$0	$60,830	$0	$174	$61,004	1.4913	$40,908
16	$0	$60,830	$0	$174	$61,004	1.5315	$39,832
17	$0	$60,830	$0	$174	$61,004	1.5729	$38,785
18	$0	$60,830	$0	$174	$61,004	1.6154	$37,765
19	$0	$60,830	$0	$174	$61,004	1.6590	$36,772
20	$0	$60,830	$0	$174	$61,004	1.7038	$35,806
21	$0	$60,830	$0	$174	$61,004	1.7498	$34,864
22	$0	$60,830	$0	$174	$61,004	1.7970	$33,948
23	$0	$60,830	$0	$174	$61,004	1.8455	$33,055
24	$0	$60,830	$0	$174	$61,004	1.8954	$32,186
25	$0	$60,830	$0	$174	$61,004	1.9465	$31,340
26	$0	$60,830	$0	$174	$61,004	1.9991	$30,516
27	$0	$60,830	$0	$174	$61,004	2.0531	$29,714
28	$0	$60,830	$0	$174	$61,004	2.1085	$28,933
29	$0	$60,830	$0	$174	$61,004	2.1654	$28,172
30	$0	$60,830	$0	$174	$61,004	2.2239	$27,431
Total:	$0	$1,824,912	$0	$5,220	$1,830,132		
				NPV:	$1,243,445		$1,243,445

LED Lighting System

Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	$935,250	-	-	-	$935,250	1.0000	$935,250
1	$0	$0	$0	$0	$0	1.0270	$0
2	$0	$0	$0	$0	$0	1.0547	$0
3	$0	$0	$0	$0	$0	1.0832	$0
4	$0	$0	$0	$0	$0	1.1125	$0
5	$0	$0	$0	$0	$0	1.1425	$0
6	$376,660	$0	$0	$0	$376,660	1.1733	$321,016
7	$0	$0	$0	$0	$0	1.2050	$0
8	$0	$0	$0	$0	$0	1.2376	$0
9	$0	$0	$0	$0	$0	1.2710	$0
10	$0	$0	$0	$0	$0	1.3053	$0
11	$359,350	$0	$0	$0	$359,350	1.3405	$268,067
12	$0	$0	$0	$0	$0	1.3767	$0
13	$0	$0	$0	$0	$0	1.4139	$0
14	$0	$0	$0	$0	$0	1.4521	$0
15	$0	$0	$0	$0	$0	1.4913	$0
16	$349,628	$0	$0	$0	$349,628	1.5315	$228,286
17	$0	$0	$0	$0	$0	1.5729	$0
18	$0	$0	$0	$0	$0	1.6154	$0
19	$0	$0	$0	$0	$0	1.6590	$0
20	$0	$0	$0	$0	$0	1.7038	$0
21	$342,905	$0	$0	$0	$342,905	1.7498	$195,972
22	$0	$0	$0	$0	$0	1.7970	$0
23	$0	$0	$0	$0	$0	1.8455	$0
24	$0	$0	$0	$0	$0	1.8954	$0
25	$0	$0	$0	$0	$0	1.9465	$0
26	$337,788	$0	$0	$0	$337,788	1.9991	$168,971
27	$0	$0	$0	$0	$0	2.0531	$0
28	$0	$0	$0	$0	$0	2.1085	$0
29	$0	$0	$0	$0	$0	2.1654	$0
30	$0	$0	$0	$0	$0	2.2239	$0
Total:	$2,701,582	$0	$0	$0	$2,701,582		
				NPV:	$2,117,562		$2,117,562

Cost Formulas:

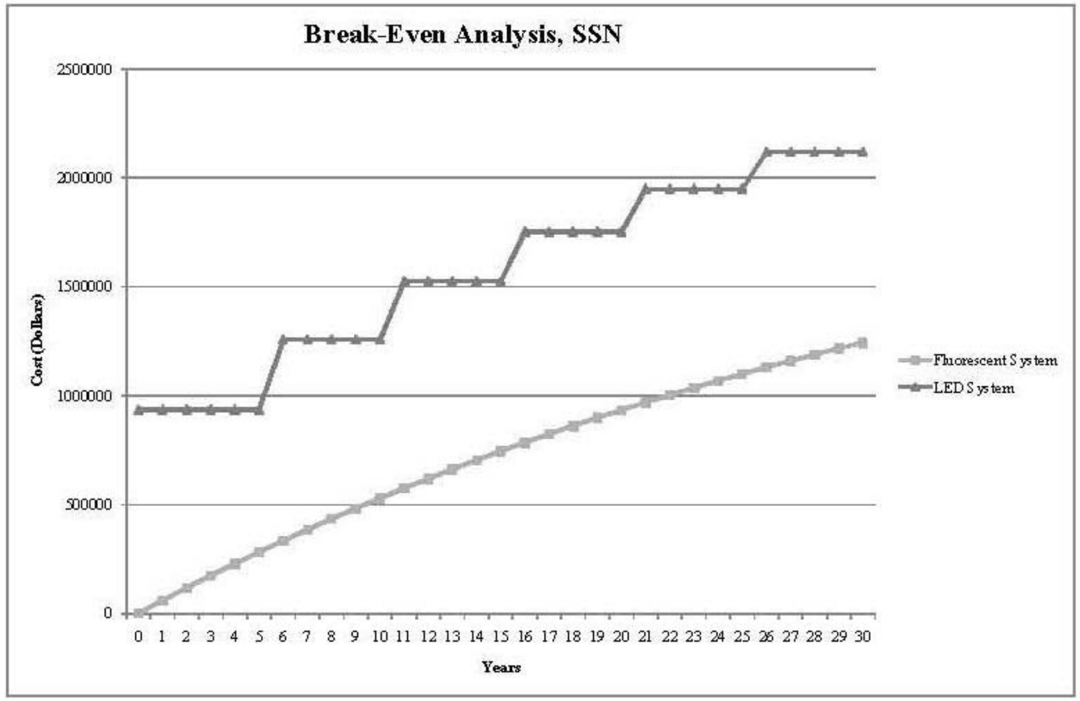
Investment: (fixtures)*(Cost per fixture)+(fixtures)*(hours to install)*(labor cost/hour)

Maintenance: (lamps replaced)*(time to replace)*(labor cost/hour)*(# of personnel)+(lamps replaced)*(cost per lamp)+(ballasts replaced)*(cost per ballast)+(starters replaced)*(cost per starter)

Operation: [(sfc*power in watts*time in hours)/8.33*746]*(price per gallon)*(days underway per year)

Disposal: (failed lamps)*(feet per lamp)*(recycle cost)

Year	FL cost, Cum PV	LED cost, Cum PV	Cum Cost Savings
0	0	$935,250	-$935,250
1	$59,401	$935,250	-$875,849
2	$117,240	$935,250	-$818,010
3	$173,558	$935,250	-$761,692
4	$228,396	$935,250	-$706,854
5	$281,792	$935,250	-$653,458
6	$333,784	$1,256,266	-$922,483
7	$384,409	$1,256,266	-$871,857
8	$433,704	$1,256,266	-$822,563
9	$481,702	$1,256,266	-$774,564
10	$528,439	$1,256,266	-$727,828
11	$573,946	$1,524,333	-$950,387
12	$618,258	$1,524,333	-$906,075
13	$661,404	$1,524,333	-$862,929
14	$703,417	$1,524,333	-$820,916
15	$744,324	$1,524,333	-$780,009
16	$784,156	$1,752,619	-$968,463
17	$822,941	$1,752,619	-$929,678
18	$860,707	$1,752,619	-$891,912
19	$897,479	$1,752,619	-$855,140
20	$933,285	$1,752,619	-$819,334
21	$968,149	$1,948,591	-$980,442
22	$1,002,097	$1,948,591	-$946,494
23	$1,035,152	$1,948,591	-$913,439
24	$1,067,339	$1,948,591	-$881,253
25	$1,098,679	$1,948,591	-$849,913
26	$1,129,195	$2,117,562	-$988,368
27	$1,158,909	$2,117,562	-$958,654
28	$1,187,841	$2,117,562	-$929,721
29	$1,216,013	$2,117,562	-$901,549
30	$1,243,445	$2,117,562	-$874,118



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$2,701,582	$0	$0	$0	$2,701,582	$2,117,562
Fluorescent	$0	$1,824,912	$0	$5,220	$1,830,132	$1,243,445

Assumptions:	Number of fixtures	Fixture cost	Fuel cost	Maint. Hours	Discount Rate	Shipyard labor cost / hour
	696	$1,300.00	$2.77	0.5	0.027	$43.75

Ohio Class SSBN/SSGN

Propulsion:	Nuclear
Number in Service:	18
Displacement (Light Tons):	15275
Number of Fixtures:	1864
Number of Lamps:	4660
Fuel Burden Factor:	0
Generator GPH:	n/a

COST COMPARISON FOR ENTIRE CLASS:	
Lifecycle Cost of Status Quo:	$59,942,611.33
Lifecycle Cost with LEDs:	$102,081,115.57
Lifecycle Cost Savings:	-$42,138,504.23

COST COMPARISON FOR ONE VESSEL:

	Fluorescent Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	-	-	-	-	-	-	-
1	$0	$162,914	$0	$466	$163,380	1.0270	$159,084
2	$0	$162,914	$0	$466	$163,380	1.0547	$154,902
3	$0	$162,914	$0	$466	$163,380	1.0832	$150,830
4	$0	$162,914	$0	$466	$163,380	1.1125	$146,864
5	$0	$162,914	$0	$466	$163,380	1.1425	$143,003
6	$0	$162,914	$0	$466	$163,380	1.1733	$139,244
7	$0	$162,914	$0	$466	$163,380	1.2050	$135,583
8	$0	$162,914	$0	$466	$163,380	1.2376	$132,018
9	$0	$162,914	$0	$466	$163,380	1.2710	$128,548
10	$0	$162,914	$0	$466	$163,380	1.3053	$125,168
11	$0	$162,914	$0	$466	$163,380	1.3405	$121,877
12	$0	$162,914	$0	$466	$163,380	1.3767	$118,673
13	$0	$162,914	$0	$466	$163,380	1.4139	$115,553
14	$0	$162,914	$0	$466	$163,380	1.4521	$112,515
15	$0	$162,914	$0	$466	$163,380	1.4913	$109,557
16	$0	$162,914	$0	$466	$163,380	1.5315	$106,677
17	$0	$162,914	$0	$466	$163,380	1.5729	$103,872
18	$0	$162,914	$0	$466	$163,380	1.6154	$101,142
19	$0	$162,914	$0	$466	$163,380	1.6590	$98,483
20	$0	$162,914	$0	$466	$163,380	1.7038	$95,893
21	$0	$162,914	$0	$466	$163,380	1.7498	$93,372
22	$0	$162,914	$0	$466	$163,380	1.7970	$90,918
23	$0	$162,914	$0	$466	$163,380	1.8455	$88,527
24	$0	$162,914	$0	$466	$163,380	1.8954	$86,200
25	$0	$162,914	$0	$466	$163,380	1.9465	$83,934
26	$0	$162,914	$0	$466	$163,380	1.9991	$81,727
27	$0	$162,914	$0	$466	$163,380	2.0531	$79,579
28	$0	$162,914	$0	$466	$163,380	2.1085	$77,486
29	$0	$162,914	$0	$466	$163,380	2.1654	$75,449
30	$0	$162,914	$0	$466	$163,380	2.2239	$73,466
Total:	$0	$4,887,408	$0	$13,980	$4,901,388		
				NPV:	$3,330,145		$3,330,145

	LED Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	$2,504,750	-	-	-	$2,504,750	1.0000	$2,504,750
1	$0	$0	$0	$0	$0	1.0270	$0
2	$0	$0	$0	$0	$0	1.0547	$0
3	$0	$0	$0	$0	$0	1.0832	$0
4	$0	$0	$0	$0	$0	1.1125	$0
5	$0	$0	$0	$0	$0	1.1425	$0
6	$1,008,757	$0	$0	$0	$1,008,757	1.1733	$859,734
7	$0	$0	$0	$0	$0	1.2050	$0
8	$0	$0	$0	$0	$0	1.2376	$0
9	$0	$0	$0	$0	$0	1.2710	$0
10	$0	$0	$0	$0	$0	1.3053	$0
11	$962,397	$0	$0	$0	$962,397	1.3405	$717,926
12	$0	$0	$0	$0	$0	1.3767	$0
13	$0	$0	$0	$0	$0	1.4139	$0
14	$0	$0	$0	$0	$0	1.4521	$0
15	$0	$0	$0	$0	$0	1.4913	$0
16	$936,360	$0	$0	$0	$936,360	1.5315	$611,387
17	$0	$0	$0	$0	$0	1.5729	$0
18	$0	$0	$0	$0	$0	1.6154	$0
19	$0	$0	$0	$0	$0	1.6590	$0
20	$0	$0	$0	$0	$0	1.7038	$0
21	$918,355	$0	$0	$0	$918,355	1.7498	$524,845
22	$0	$0	$0	$0	$0	1.7970	$0
23	$0	$0	$0	$0	$0	1.8455	$0
24	$0	$0	$0	$0	$0	1.8954	$0
25	$0	$0	$0	$0	$0	1.9465	$0
26	$904,651	$0	$0	$0	$904,651	1.9991	$452,532
27	$0	$0	$0	$0	$0	2.0531	$0
28	$0	$0	$0	$0	$0	2.1085	$0
29	$0	$0	$0	$0	$0	2.1654	$0
30	$0	$0	$0	$0	$0	2.2239	$0
Total:	$7,235,270	$0	$0	$0	$7,235,270		
				NPV:	$5,671,173		$5,671,173

Cost Formulas:

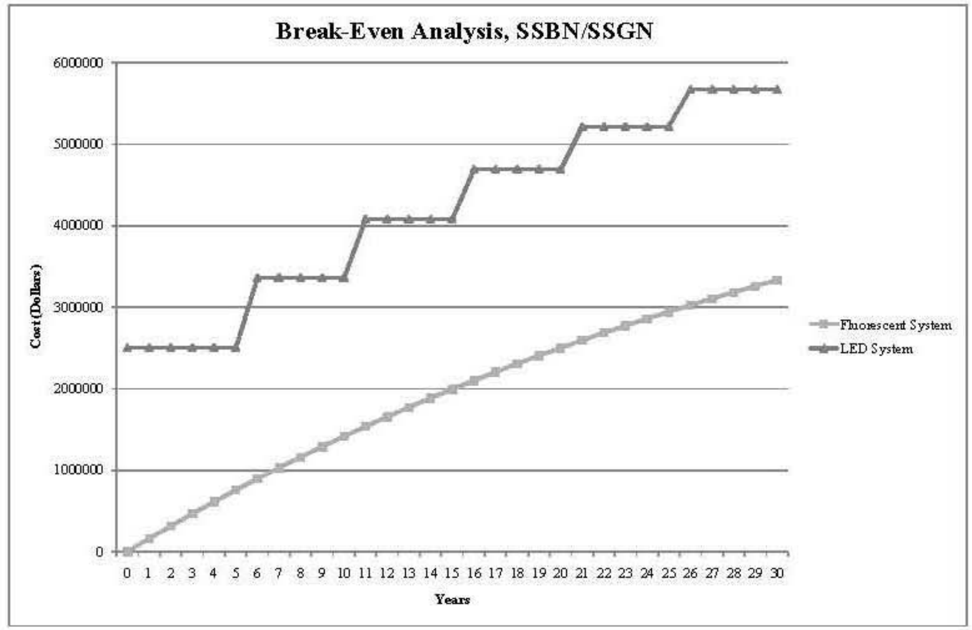
Investment: (fixtures)*(Cost per fixture)+(fixtures)*(hours to install)*(labor cost/hour)

Maintenance: (lamps replaced)*(time to replace)*(labor cost/hour)*(# of personnel)+(lamps replaced)*(cost per lamp)+(ballasts replaced)*(cost per ballast)+(starters replaced)*(cost per starter)

Operation: [(sfc*power in watts*time in hours)/8.33*746]*(price per gallon)*(days underway per year)

Disposal: (failed lamps)*(feet per lamp)*(recycle cost)

Year	FL cost, Cum PV	LED cost, Cum PV	Cum Cost Savings
0	0	$2,504,750	-$2,504,750
1	$159,084	$2,504,750	-$2,345,666
2	$313,986	$2,504,750	-$2,190,764
3	$464,816	$2,504,750	-$2,039,934
4	$611,680	$2,504,750	-$1,893,070
5	$754,683	$2,504,750	-$1,750,067
6	$893,927	$3,364,484	-$2,470,557
7	$1,029,510	$3,364,484	-$2,334,974
8	$1,161,528	$3,364,484	-$2,202,956
9	$1,290,076	$3,364,484	-$2,074,408
10	$1,415,244	$3,364,484	-$1,949,240
11	$1,537,121	$4,082,409	-$2,545,288
12	$1,655,794	$4,082,409	-$2,426,615
13	$1,771,347	$4,082,409	-$2,311,062
14	$1,883,863	$4,082,409	-$2,198,546
15	$1,993,420	$4,082,409	-$2,088,989
16	$2,100,097	$4,693,796	-$2,593,699
17	$2,203,969	$4,693,796	-$2,489,826
18	$2,305,111	$4,693,796	-$2,388,685
19	$2,403,593	$4,693,796	-$2,290,202
20	$2,499,487	$4,693,796	-$2,194,309
21	$2,592,859	$5,218,641	-$2,625,782
22	$2,683,777	$5,218,641	-$2,534,864
23	$2,772,304	$5,218,641	-$2,446,337
24	$2,858,504	$5,218,641	-$2,360,137
25	$2,942,438	$5,218,641	-$2,276,203
26	$3,024,165	$5,671,173	-$2,647,008
27	$3,103,744	$5,671,173	-$2,567,429
28	$3,181,230	$5,671,173	-$2,489,943
29	$3,256,679	$5,671,173	-$2,414,494
30	$3,330,145	$5,671,173	-$2,341,028



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$7,235,270	$0	$0	$0	$7,235,270	*$5,671,173*
Fluorescent	$0	$4,887,408	$0	$13,980	$4,901,388	*$3,330,145*

Assumptions:	Number of fixtures	Fixture cost	Fuel cost	Maint. Hours	Discount Rate	Shipyard labor cost / hour
	1864	$1,300.00	$2.77	0.5	0.027	$43.75

LHA/LHD

	Wasp	Tarawa	
Propulsion:	Steam	Steam	
Number in Service:	7	2	
Displacement (Light Tons):	28050	25884	
Number of Fixtures:	7015	7015	(weighted average)
Number of Lamps:	17327	17327	
Fuel Burden Factor:	1	1	
Generator GPH:	140.2	140.2	

COST COMPARISON FOR ENTIRE CLASS:	
Lifecycle Cost of Status Quo:	$143,499,703.58
Lifecycle Cost with LEDs:	$200,101,364.56
Lifecycle Cost Savings:	-$56,601,660.97

COST COMPARISON FOR ONE VESSEL:

	Fluorescent Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	-	-	-	-	-	-	-
1	$0	$605,754	$174,759	$1,733	$782,246	1.0270	$761,680
2	$0	$605,754	$174,759	$1,733	$782,246	1.0547	$741,656
3	$0	$605,754	$174,759	$1,733	$782,246	1.0832	$722,157
4	$0	$605,754	$174,759	$1,733	$782,246	1.1125	$703,172
5	$0	$605,754	$174,759	$1,733	$782,246	1.1425	$684,685
6	$0	$605,754	$174,759	$1,733	$782,246	1.1733	$666,685
7	$0	$605,754	$174,759	$1,733	$782,246	1.2050	$649,157
8	$0	$605,754	$174,759	$1,733	$782,246	1.2376	$632,091
9	$0	$605,754	$174,759	$1,733	$782,246	1.2710	$615,473
10	$0	$605,754	$174,759	$1,733	$782,246	1.3053	$599,292
11	$0	$605,754	$174,759	$1,733	$782,246	1.3405	$583,537
12	$0	$605,754	$174,759	$1,733	$782,246	1.3767	$568,196
13	$0	$605,754	$174,759	$1,733	$782,246	1.4139	$553,258
14	$0	$605,754	$174,759	$1,733	$782,246	1.4521	$538,712
15	$0	$605,754	$174,759	$1,733	$782,246	1.4913	$524,550
16	$0	$605,754	$174,759	$1,733	$782,246	1.5315	$510,759
17	$0	$605,754	$174,759	$1,733	$782,246	1.5729	$497,331
18	$0	$605,754	$174,759	$1,733	$782,246	1.6154	$484,256
19	$0	$605,754	$174,759	$1,733	$782,246	1.6590	$471,525
20	$0	$605,754	$174,759	$1,733	$782,246	1.7038	$459,129
21	$0	$605,754	$174,759	$1,733	$782,246	1.7498	$447,058
22	$0	$605,754	$174,759	$1,733	$782,246	1.7970	$435,305
23	$0	$605,754	$174,759	$1,733	$782,246	1.8455	$423,861
24	$0	$605,754	$174,759	$1,733	$782,246	1.8954	$412,717
25	$0	$605,754	$174,759	$1,733	$782,246	1.9465	$401,867
26	$0	$605,754	$174,759	$1,733	$782,246	1.9991	$391,302
27	$0	$605,754	$174,759	$1,733	$782,246	2.0531	$381,014
28	$0	$605,754	$174,759	$1,733	$782,246	2.1085	$370,997
29	$0	$605,754	$174,759	$1,733	$782,246	2.1654	$361,244
30	$0	$605,754	$174,759	$1,733	$782,246	2.2239	$351,747
Total:	$0	$18,172,610	$5,242,779	$51,981	$23,467,370		
				NPV:	$15,944,412		$15,944,412

	LED Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	$9,426,406	-	-	-	$9,426,406	1.0000	$9,426,406
1	$0	$0	$43,690	$0	$43,690	1.0270	$42,541
2	$0	$0	$43,690	$0	$43,690	1.0547	$41,423
3	$0	$0	$43,690	$0	$43,690	1.0832	$40,334
4	$0	$0	$43,690	$0	$43,690	1.1125	$39,273
5	$0	$0	$43,690	$0	$43,690	1.1425	$38,241
6	$3,796,368	$0	$43,690	$0	$3,840,058	1.1733	$3,272,767
7	$0	$0	$43,690	$0	$43,690	1.2050	$36,257
8	$0	$0	$43,690	$0	$43,690	1.2376	$35,303
9	$0	$0	$43,690	$0	$43,690	1.2710	$34,375
10	$0	$0	$43,690	$0	$43,690	1.3053	$33,472
11	$3,621,897	$0	$43,690	$0	$3,665,586	1.3405	$2,734,441
12	$0	$0	$43,690	$0	$43,690	1.3767	$31,735
13	$0	$0	$43,690	$0	$43,690	1.4139	$30,900
14	$0	$0	$43,690	$0	$43,690	1.4521	$30,088
15	$0	$0	$43,690	$0	$43,690	1.4913	$29,297
16	$3,523,910	$0	$43,690	$0	$3,567,600	1.5315	$2,329,426
17	$0	$0	$43,690	$0	$43,690	1.5729	$27,777
18	$0	$0	$43,690	$0	$43,690	1.6154	$27,047
19	$0	$0	$43,690	$0	$43,690	1.6590	$26,336
20	$0	$0	$43,690	$0	$43,690	1.7038	$25,643
21	$3,456,148	$0	$43,690	$0	$3,499,838	1.7498	$2,000,178
22	$0	$0	$43,690	$0	$43,690	1.7970	$24,313
23	$0	$0	$43,690	$0	$43,690	1.8455	$23,673
24	$0	$0	$43,690	$0	$43,690	1.8954	$23,051
25	$0	$0	$43,690	$0	$43,690	1.9465	$22,445
26	$3,404,573	$0	$43,690	$0	$3,448,263	1.9991	$1,724,920
27	$0	$0	$43,690	$0	$43,690	2.0531	$21,280
28	$0	$0	$43,690	$0	$43,690	2.1085	$20,721
29	$0	$0	$43,690	$0	$43,690	2.1654	$20,176
30	$0	$0	$43,690	$0	$43,690	2.2239	$19,646
Total:	$27,229,302	$0	$1,310,695	$0	$28,539,997		
				NPV:	$22,233,485		$22,233,485

Cost Formulas:

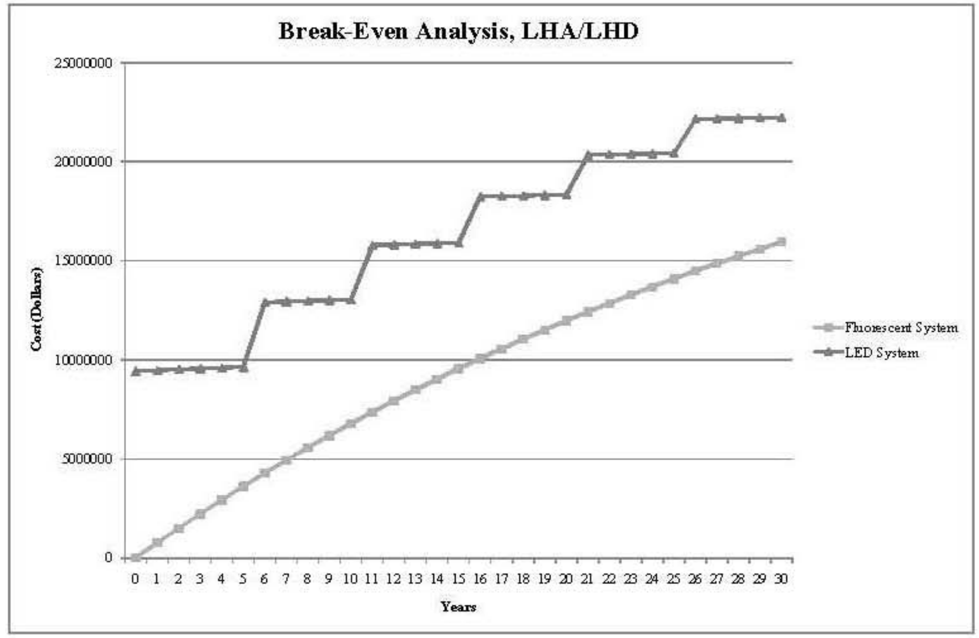
Investment: (fixtures)*(Cost per fixture)+(fixtures)*(hours to install)*(labor cost/hour)

Maintenance: (lamps replaced)*(time to replace)*(labor cost/hour)*(# of personnel)+(lamps replaced)*(cost per lamp)+(ballasts replaced)*(cost per ballast)+(starters replaced)*(cost per starter)

Operation: (gallons/hour)*(price per gallon)*(fuel burden factor)*(20 hours/day)*(days underway per year)*(number of generators-1)*5%

Disposal: (failed lamps)*(feet per lamp)*(recycle cost)

Year	FL cost, Cum PV	LED cost, Cum PV	Cum Cost Savings
0	0	$9,426,406	-$9,426,406
1	$761,680	$9,468,947	-$8,707,267
2	$1,503,336	$9,510,370	-$8,007,034
3	$2,225,493	$9,550,704	-$7,325,211
4	$2,928,665	$9,589,977	-$6,661,312
5	$3,613,350	$9,628,218	-$6,014,868
6	$4,280,035	$12,900,986	-$8,620,951
7	$4,929,192	$12,937,242	-$8,008,050
8	$5,561,283	$12,972,546	-$7,411,262
9	$6,176,757	$13,006,921	-$6,830,164
10	$6,776,049	$13,040,392	-$6,264,343
11	$7,359,586	$15,774,834	-$8,415,248
12	$7,927,781	$15,806,568	-$7,878,787
13	$8,481,039	$15,837,469	-$7,356,430
14	$9,019,751	$15,867,557	-$6,847,805
15	$9,544,301	$15,896,854	-$6,352,553
16	$10,055,060	$18,226,280	-$8,171,220
17	$10,552,391	$18,254,057	-$7,701,666
18	$11,036,647	$18,281,104	-$7,244,456
19	$11,508,172	$18,307,439	-$6,799,267
20	$11,967,301	$18,333,082	-$6,365,781
21	$12,414,359	$20,333,260	-$7,918,902
22	$12,849,664	$20,357,573	-$7,507,909
23	$13,273,524	$20,381,246	-$7,107,722
24	$13,686,241	$20,404,297	-$6,718,056
25	$14,088,108	$20,426,742	-$6,338,634
26	$14,479,410	$22,151,662	-$7,672,252
27	$14,860,424	$22,172,942	-$7,312,518
28	$15,231,421	$22,193,663	-$6,962,242
29	$15,592,665	$22,213,839	-$6,621,174
30	$15,944,412	$22,233,485	-$6,289,073



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$27,229,302	$0	$1,310,695	$0	$28,539,997	$22,233,485
Fluorescent	$0	$18,172,610	$5,242,779	$51,981	$23,467,370	$15,944,412

Assumptions:	Number of fixtures	Fixture cost	Fuel cost	Maint. Hours	Discount Rate	Shipyard labor cost / hour
	7015	$1,300.00	$2.77	0.5	0.027	$43.75

LPD

	Austin	San Antonio
Propulsion:	Steam	Diesel
Number in Service:	7	4
Displacement (Light Tons):	9734	19013
Number of Fixtures:	3335	3335 (weighted average)
Number of Lamps:	8237	8237
Fuel Burden Factor:	1	1
Generator GPH:	147.2	150.0

COST COMPARISON FOR ENTIRE CLASS:	
Lifecycle Cost of Status Quo:	$105,892,834.55
Lifecycle Cost with LEDs:	$121,898,042.76
Lifecycle Cost Savings:	-$16,005,208.21

COST COMPARISON FOR ONE VESSEL:

	Fluorescent Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	-	-	-	-	-	-	-
1	$0	$287,981	$183,485	$824	$472,290	1.0270	$459,873
2	$0	$287,981	$183,485	$824	$472,290	1.0547	$447,783
3	$0	$287,981	$183,485	$824	$472,290	1.0832	$436,011
4	$0	$287,981	$183,485	$824	$472,290	1.1125	$424,548
5	$0	$287,981	$183,485	$824	$472,290	1.1425	$413,387
6	$0	$287,981	$183,485	$824	$472,290	1.1733	$402,519
7	$0	$287,981	$183,485	$824	$472,290	1.2050	$391,936
8	$0	$287,981	$183,485	$824	$472,290	1.2376	$381,632
9	$0	$287,981	$183,485	$824	$472,290	1.2710	$371,599
10	$0	$287,981	$183,485	$824	$472,290	1.3053	$361,830
11	$0	$287,981	$183,485	$824	$472,290	1.3405	$352,317
12	$0	$287,981	$183,485	$824	$472,290	1.3767	$343,055
13	$0	$287,981	$183,485	$824	$472,290	1.4139	$334,036
14	$0	$287,981	$183,485	$824	$472,290	1.4521	$325,254
15	$0	$287,981	$183,485	$824	$472,290	1.4913	$316,703
16	$0	$287,981	$183,485	$824	$472,290	1.5315	$308,377
17	$0	$287,981	$183,485	$824	$472,290	1.5729	$300,269
18	$0	$287,981	$183,485	$824	$472,290	1.6154	$292,375
19	$0	$287,981	$183,485	$824	$472,290	1.6590	$284,689
20	$0	$287,981	$183,485	$824	$472,290	1.7038	$277,204
21	$0	$287,981	$183,485	$824	$472,290	1.7498	$269,916
22	$0	$287,981	$183,485	$824	$472,290	1.7970	$262,820
23	$0	$287,981	$183,485	$824	$472,290	1.8455	$255,911
24	$0	$287,981	$183,485	$824	$472,290	1.8954	$249,183
25	$0	$287,981	$183,485	$824	$472,290	1.9465	$242,632
26	$0	$287,981	$183,485	$824	$472,290	1.9991	$236,253
27	$0	$287,981	$183,485	$824	$472,290	2.0531	$230,042
28	$0	$287,981	$183,485	$824	$472,290	2.1085	$223,994
29	$0	$287,981	$183,485	$824	$472,290	2.1654	$218,105
30	$0	$287,981	$183,485	$824	$472,290	2.2239	$212,371
Total:	$0	$8,639,438	$5,504,544	$24,712	$14,168,694		
				NPV:	$9,626,621		$9,626,621

	LED Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	$4,481,406	-	-	-	$4,481,406	1.0000	$4,481,406
1	$0	$0	$45,871	$0	$45,871	1.0270	$44,665
2	$0	$0	$45,871	$0	$45,871	1.0547	$43,491
3	$0	$0	$45,871	$0	$45,871	1.0832	$42,348
4	$0	$0	$45,871	$0	$45,871	1.1125	$41,234
5	$0	$0	$45,871	$0	$45,871	1.1425	$40,150
6	$1,804,831	$0	$45,871	$0	$1,850,702	1.1733	$1,577,298
7	$0	$0	$45,871	$0	$45,871	1.2050	$38,067
8	$0	$0	$45,871	$0	$45,871	1.2376	$37,066
9	$0	$0	$45,871	$0	$45,871	1.2710	$36,092
10	$0	$0	$45,871	$0	$45,871	1.3053	$35,143
11	$1,721,885	$0	$45,871	$0	$1,767,756	1.3405	$1,318,705
12	$0	$0	$45,871	$0	$45,871	1.3767	$33,319
13	$0	$0	$45,871	$0	$45,871	1.4139	$32,443
14	$0	$0	$45,871	$0	$45,871	1.4521	$31,590
15	$0	$0	$45,871	$0	$45,871	1.4913	$30,760
16	$1,675,301	$0	$45,871	$0	$1,721,173	1.5315	$1,123,821
17	$0	$0	$45,871	$0	$45,871	1.5729	$29,164
18	$0	$0	$45,871	$0	$45,871	1.6154	$28,397
19	$0	$0	$45,871	$0	$45,871	1.6590	$27,650
20	$0	$0	$45,871	$0	$45,871	1.7038	$26,923
21	$1,643,087	$0	$45,871	$0	$1,688,958	1.7498	$965,249
22	$0	$0	$45,871	$0	$45,871	1.7970	$25,526
23	$0	$0	$45,871	$0	$45,871	1.8455	$24,855
24	$0	$0	$45,871	$0	$45,871	1.8954	$24,202
25	$0	$0	$45,871	$0	$45,871	1.9465	$23,566
26	$1,618,568	$0	$45,871	$0	$1,664,439	1.9991	$832,600
27	$0	$0	$45,871	$0	$45,871	2.0531	$22,343
28	$0	$0	$45,871	$0	$45,871	2.1085	$21,755
29	$0	$0	$45,871	$0	$45,871	2.1654	$21,183
30	$0	$0	$45,871	$0	$45,871	2.2239	$20,627
Total:	$12,945,078	$0	$1,376,136	$0	$14,321,214		
				NPV:	$11,081,640		$11,081,640

Cost Formulas:

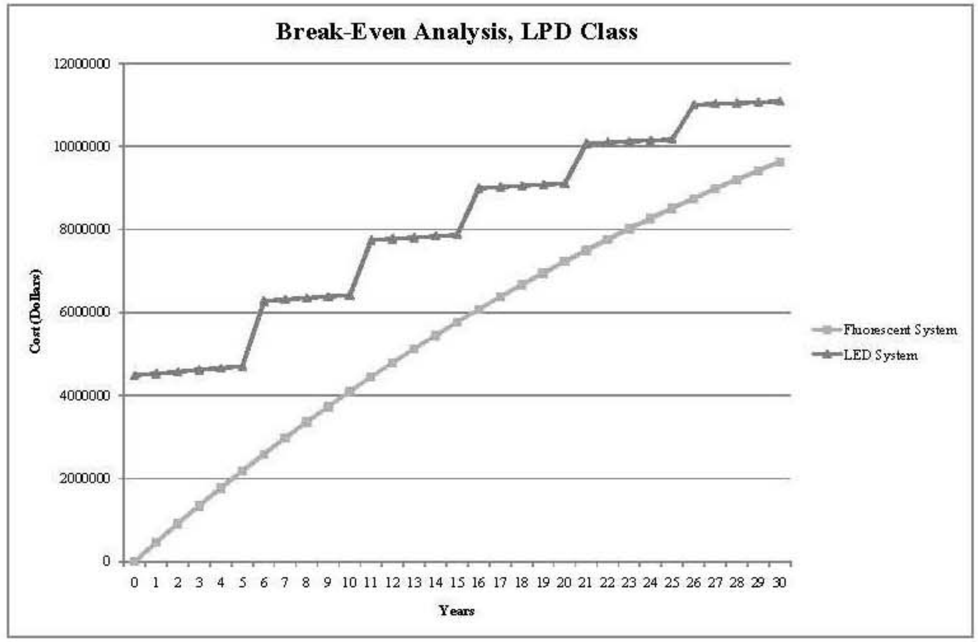
Investment: (fixtures)*(Cost per fixture)+(fixtures)*(hours to install)*(labor cost/hour)

Maintenance: (lamps replaced)*(time to replace)*(labor cost/hour)*(# of personnel)+(lamps replaced)*(cost per lamp)+(ballasts replaced)*(cost per ballast)+(starters replaced)*(cost per starter)

Operation: (gallons/hour)*(price per gallon)*(fuel burden factor)*(20 hours/day)*(days underway per year)*(number of generators-1)*5%

Disposal: (failed lamps)*(feet per lamp)*(recycle cost)

Year	FL cost, Cum PV	LED cost, Cum PV	Cum Cost Savings
0	0	$4,481,406	-$4,481,406
1	$459,873	$4,526,071	-$4,066,198
2	$907,656	$4,569,562	-$3,661,906
3	$1,343,667	$4,611,910	-$3,268,243
4	$1,768,215	$4,653,144	-$2,884,929
5	$2,181,602	$4,693,295	-$2,511,693
6	$2,584,120	$6,270,593	-$3,686,473
7	$2,976,056	$6,308,660	-$3,332,603
8	$3,357,689	$6,345,726	-$2,988,037
9	$3,729,288	$6,381,817	-$2,652,530
10	$4,091,117	$6,416,960	-$2,325,843
11	$4,443,434	$7,735,665	-$3,292,230
12	$4,786,489	$7,768,984	-$2,982,495
13	$5,120,525	$7,801,427	-$2,680,903
14	$5,445,778	$7,833,018	-$2,387,239
15	$5,762,481	$7,863,777	-$2,101,296
16	$6,070,858	$8,987,599	-$2,916,741
17	$6,371,127	$9,016,762	-$2,645,635
18	$6,663,502	$9,045,159	-$2,381,657
19	$6,948,191	$9,072,810	-$2,124,619
20	$7,225,395	$9,099,733	-$1,874,338
21	$7,495,312	$10,064,983	-$2,569,671
22	$7,758,132	$10,090,509	-$2,332,377
23	$8,014,042	$10,115,365	-$2,101,322
24	$8,263,225	$10,139,567	-$1,876,341
25	$8,505,857	$10,163,132	-$1,657,275
26	$8,742,110	$10,995,732	-$2,253,622
27	$8,972,151	$11,018,075	-$2,045,923
28	$9,196,145	$11,039,830	-$1,843,685
29	$9,414,250	$11,061,014	-$1,646,763
30	$9,626,621	$11,081,640	-$1,455,019



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$12,945,078	$0	$1,376,136	$0	$14,321,214	$11,081,640
Fluorescent	$0	$8,639,438	$5,504,544	$24,712	$14,168,694	$9,626,621

Assumptions:	Number of fixtures	Fixture cost	Fuel cost	Maint. Hours	Discount Rate	Shipyard labor cost / hour
	3335	$1,300.00	$2.77	0.5	0.027	$43.75

LSD Class

	Whidbey Isl.	Harpers Ferry
Propulsion:	Diesel	Diesel
Number in Service:	8	4
Displacement (Light Tons):	11471	11604
Number of Fixtures:	2919	2952
Number of Lamps:	7210	7291
Fuel Burden Factor:	1	1
Generator GPH:	80.5	80.5

COST COMPARISON FOR ENTIRE CLASS:	
Lifecycle Cost of Status Quo:	$86,372,017.34
Lifecycle Cost with LEDs:	$112,707,658.54
Lifecycle Cost Savings:	-$26,335,641.20

COST COMPARISON FOR ONE VESSEL:

	Fluorescent Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	-	-	-	-	-	-	-
1	$0	$252,059	$100,343	$721	$353,123	1.0270	$343,840
2	$0	$252,059	$100,343	$721	$353,123	1.0547	$334,800
3	$0	$252,059	$100,343	$721	$353,123	1.0832	$325,998
4	$0	$252,059	$100,343	$721	$353,123	1.1125	$317,428
5	$0	$252,059	$100,343	$721	$353,123	1.1425	$309,082
6	$0	$252,059	$100,343	$721	$353,123	1.1733	$300,957
7	$0	$252,059	$100,343	$721	$353,123	1.2050	$293,044
8	$0	$252,059	$100,343	$721	$353,123	1.2376	$285,340
9	$0	$252,059	$100,343	$721	$353,123	1.2710	$277,839
10	$0	$252,059	$100,343	$721	$353,123	1.3053	$270,534
11	$0	$252,059	$100,343	$721	$353,123	1.3405	$263,422
12	$0	$252,059	$100,343	$721	$353,123	1.3767	$256,496
13	$0	$252,059	$100,343	$721	$353,123	1.4139	$249,753
14	$0	$252,059	$100,343	$721	$353,123	1.4521	$243,187
15	$0	$252,059	$100,343	$721	$353,123	1.4913	$236,794
16	$0	$252,059	$100,343	$721	$353,123	1.5315	$230,568
17	$0	$252,059	$100,343	$721	$353,123	1.5729	$224,507
18	$0	$252,059	$100,343	$721	$353,123	1.6154	$218,604
19	$0	$252,059	$100,343	$721	$353,123	1.6590	$212,857
20	$0	$252,059	$100,343	$721	$353,123	1.7038	$207,261
21	$0	$252,059	$100,343	$721	$353,123	1.7498	$201,812
22	$0	$252,059	$100,343	$721	$353,123	1.7970	$196,506
23	$0	$252,059	$100,343	$721	$353,123	1.8455	$191,340
24	$0	$252,059	$100,343	$721	$353,123	1.8954	$186,310
25	$0	$252,059	$100,343	$721	$353,123	1.9465	$181,412
26	$0	$252,059	$100,343	$721	$353,123	1.9991	$176,642
27	$0	$252,059	$100,343	$721	$353,123	2.0531	$171,998
28	$0	$252,059	$100,343	$721	$353,123	2.1085	$167,477
29	$0	$252,059	$100,343	$721	$353,123	2.1654	$163,074
30	$0	$252,059	$100,343	$721	$353,123	2.2239	$158,786
Total:	$0	$7,561,775	$3,010,298	$21,630	$10,593,702		
				NPV:	$7,197,668		$7,197,668

	LED Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	$3,922,406	-	-	-	$3,922,406	1.0000	$3,922,406
1	$0	$0	$25,086	$0	$25,086	1.0270	$24,426
2	$0	$0	$25,086	$0	$25,086	1.0547	$23,784
3	$0	$0	$25,086	$0	$25,086	1.0832	$23,159
4	$0	$0	$25,086	$0	$25,086	1.1125	$22,550
5	$0	$0	$25,086	$0	$25,086	1.1425	$21,957
6	$1,579,700	$0	$25,086	$0	$1,604,786	1.1733	$1,367,712
7	$0	$0	$25,086	$0	$25,086	1.2050	$20,818
8	$0	$0	$25,086	$0	$25,086	1.2376	$20,271
9	$0	$0	$25,086	$0	$25,086	1.2710	$19,738
10	$0	$0	$25,086	$0	$25,086	1.3053	$19,219
11	$1,507,101	$0	$25,086	$0	$1,532,187	1.3405	$1,142,976
12	$0	$0	$25,086	$0	$25,086	1.3767	$18,221
13	$0	$0	$25,086	$0	$25,086	1.4139	$17,742
14	$0	$0	$25,086	$0	$25,086	1.4521	$17,276
15	$0	$0	$25,086	$0	$25,086	1.4913	$16,822
16	$1,466,328	$0	$25,086	$0	$1,491,414	1.5315	$973,803
17	$0	$0	$25,086	$0	$25,086	1.5729	$15,949
18	$0	$0	$25,086	$0	$25,086	1.6154	$15,530
19	$0	$0	$25,086	$0	$25,086	1.6590	$15,121
20	$0	$0	$25,086	$0	$25,086	1.7038	$14,724
21	$1,438,132	$0	$25,086	$0	$1,463,218	1.7498	$836,238
22	$0	$0	$25,086	$0	$25,086	1.7970	$13,960
23	$0	$0	$25,086	$0	$25,086	1.8455	$13,593
24	$0	$0	$25,086	$0	$25,086	1.8954	$13,235
25	$0	$0	$25,086	$0	$25,086	1.9465	$12,887
26	$1,416,671	$0	$25,086	$0	$1,441,757	1.9991	$721,208
27	$0	$0	$25,086	$0	$25,086	2.0531	$12,219
28	$0	$0	$25,086	$0	$25,086	2.1085	$11,898
29	$0	$0	$25,086	$0	$25,086	2.1654	$11,585
30	$0	$0	$25,086	$0	$25,086	2.2239	$11,280
Total:	$11,330,340	$0	$752,574	$0	$12,082,914		
				NPV:	$9,392,305		$9,392,305

Cost Formulas:

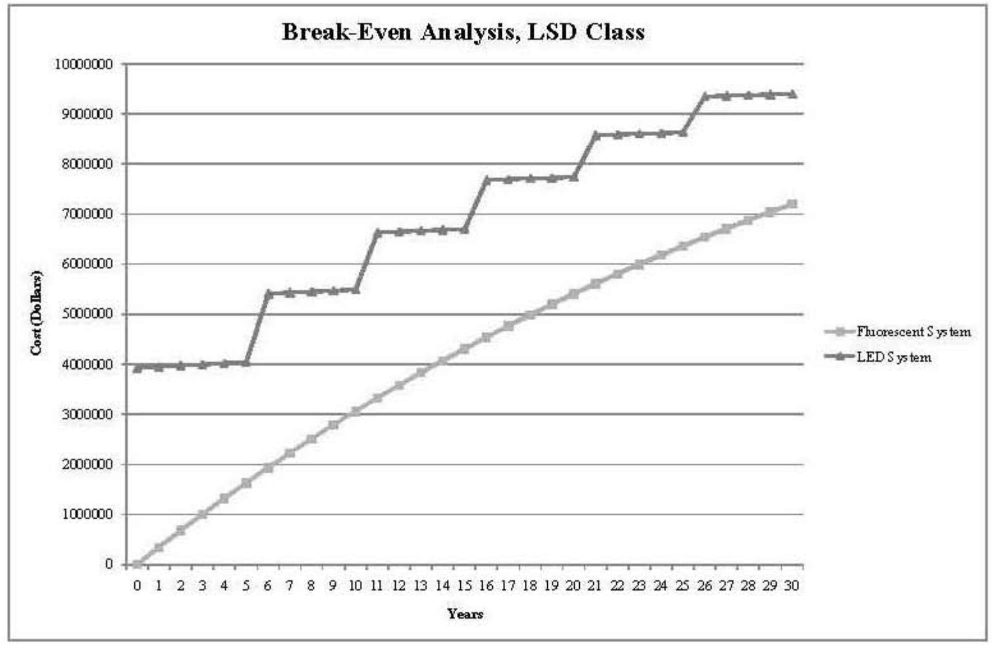
Investment: (fixtures)*(Cost per fixture)+(fixtures)*(hours to install)*(labor cost/hour)

Maintenance: (lamps replaced)*(time to replace)*(labor cost/hour)*(# of personnel)+(lamps replaced)*(cost per lamp)+(ballasts replaced)*(cost per ballast)+(starters replaced)*(cost per starter)

Operation: (gallons/hour)*(price per gallon)*(fuel burden factor)*(20 hours/day)*(days underway per year)*(number of generators-1)*10%

Disposal: (failed lamps)*(feet per lamp)*(recycle cost)

Year	FL cost, Cum PV	LED cost, Cum PV	Cum Cost Savings
0	0	$3,922,406	-$3,922,406
1	$343,840	$3,946,833	-$3,602,993
2	$678,640	$3,970,617	-$3,291,977
3	$1,004,638	$3,993,776	-$2,989,138
4	$1,322,066	$4,016,326	-$2,694,260
5	$1,631,148	$4,038,283	-$2,407,135
6	$1,932,105	$5,405,994	-$3,473,890
7	$2,225,149	$5,426,812	-$3,201,663
8	$2,510,489	$5,447,083	-$2,936,593
9	$2,788,328	$5,466,820	-$2,678,492
10	$3,058,862	$5,486,039	-$2,427,177
11	$3,322,284	$6,629,014	-$3,306,731
12	$3,578,780	$6,647,236	-$3,068,456
13	$3,828,533	$6,664,978	-$2,836,445
14	$4,071,720	$6,682,254	-$2,610,534
15	$4,308,513	$6,699,076	-$2,390,563
16	$4,539,082	$7,672,879	-$3,133,797
17	$4,763,588	$7,688,828	-$2,925,240
18	$4,982,192	$7,704,358	-$2,722,165
19	$5,195,049	$7,719,479	-$2,524,429
20	$5,402,310	$7,734,203	-$2,331,892
21	$5,604,122	$8,570,440	-$2,966,318
22	$5,800,629	$8,584,400	-$2,783,771
23	$5,991,969	$8,597,993	-$2,606,024
24	$6,178,279	$8,611,228	-$2,432,949
25	$6,359,691	$8,624,116	-$2,264,425
26	$6,536,333	$9,345,324	-$2,808,991
27	$6,708,332	$9,357,543	-$2,649,211
28	$6,875,808	$9,369,440	-$2,493,632
29	$7,038,882	$9,381,025	-$2,342,143
30	$7,197,668	$9,392,305	-$2,194,637



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$11,330,340	$0	$752,574	$0	$12,082,914	*$9,392,305*
Fluorescent	$0	$7,561,775	$3,010,298	$21,630	$10,593,702	*$7,197,668*

Assumptions:	Number of fixtures	Fixture cost	Fuel cost	Maint. Hours	Discount Rate	Shipyard labor cost / hour
	2919	$1,300.00	$2.77	0.5	0.027	$43.75

Amphibious Command and Submarine Tenders

	Blue Ridge	Emory Land
Propulsion:	Steam	Steam
Number in Service:	2	2
Displacement (Light Tons):	13038	13991
Number of Fixtures:	3317	3560
Number of Lamps:	8193	8793
Fuel Burden Factor:	1	1
Generator GPH:	140.2	140.2

COST COMPARISON FOR ENTIRE CLASS:	
Lifecycle Cost of Status Quo:	$32,918,532.40
Lifecycle Cost with LEDs:	$42,742,286.75
Lifecycle Cost Savings:	-$9,823,754.35

COST COMPARISON FOR ONE VESSEL:

	Fluorescent Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	-	-	-	-	-	-	-
1	$0	$286,427	$116,506	$819	$403,752	1.0270	$393,138
2	$0	$286,427	$116,506	$819	$403,752	1.0547	$382,802
3	$0	$286,427	$116,506	$819	$403,752	1.0832	$372,738
4	$0	$286,427	$116,506	$819	$403,752	1.1125	$362,939
5	$0	$286,427	$116,506	$819	$403,752	1.1425	$353,397
6	$0	$286,427	$116,506	$819	$403,752	1.1733	$344,106
7	$0	$286,427	$116,506	$819	$403,752	1.2050	$335,060
8	$0	$286,427	$116,506	$819	$403,752	1.2376	$326,251
9	$0	$286,427	$116,506	$819	$403,752	1.2710	$317,674
10	$0	$286,427	$116,506	$819	$403,752	1.3053	$309,322
11	$0	$286,427	$116,506	$819	$403,752	1.3405	$301,190
12	$0	$286,427	$116,506	$819	$403,752	1.3767	$293,271
13	$0	$286,427	$116,506	$819	$403,752	1.4139	$285,561
14	$0	$286,427	$116,506	$819	$403,752	1.4521	$278,054
15	$0	$286,427	$116,506	$819	$403,752	1.4913	$270,744
16	$0	$286,427	$116,506	$819	$403,752	1.5315	$263,626
17	$0	$286,427	$116,506	$819	$403,752	1.5729	$256,695
18	$0	$286,427	$116,506	$819	$403,752	1.6154	$249,947
19	$0	$286,427	$116,506	$819	$403,752	1.6590	$243,375
20	$0	$286,427	$116,506	$819	$403,752	1.7038	$236,977
21	$0	$286,427	$116,506	$819	$403,752	1.7498	$230,747
22	$0	$286,427	$116,506	$819	$403,752	1.7970	$224,681
23	$0	$286,427	$116,506	$819	$403,752	1.8455	$218,774
24	$0	$286,427	$116,506	$819	$403,752	1.8954	$213,022
25	$0	$286,427	$116,506	$819	$403,752	1.9465	$207,422
26	$0	$286,427	$116,506	$819	$403,752	1.9991	$201,968
27	$0	$286,427	$116,506	$819	$403,752	2.0531	$196,659
28	$0	$286,427	$116,506	$819	$403,752	2.1085	$191,489
29	$0	$286,427	$116,506	$819	$403,752	2.1654	$186,454
30	$0	$286,427	$116,506	$819	$403,752	2.2239	$181,552
Total:	$0	$8,592,808	$3,495,186	$24,579	$12,112,573		
				NPV:	$8,229,633		$8,229,633

	LED Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	$4,457,219	-	-	-	$4,457,219	1.0000	$4,457,219
1	$0	$0	$29,127	$0	$29,127	1.0270	$28,361
2	$0	$0	$29,127	$0	$29,127	1.0547	$27,615
3	$0	$0	$29,127	$0	$29,127	1.0832	$26,889
4	$0	$0	$29,127	$0	$29,127	1.1125	$26,182
5	$0	$0	$29,127	$0	$29,127	1.1425	$25,494
6	$1,795,090	$0	$29,127	$0	$1,824,216	1.1733	$1,554,725
7	$0	$0	$29,127	$0	$29,127	1.2050	$24,171
8	$0	$0	$29,127	$0	$29,127	1.2376	$23,536
9	$0	$0	$29,127	$0	$29,127	1.2710	$22,917
10	$0	$0	$29,127	$0	$29,127	1.3053	$22,314
11	$1,712,592	$0	$29,127	$0	$1,741,718	1.3405	$1,299,281
12	$0	$0	$29,127	$0	$29,127	1.3767	$21,156
13	$0	$0	$29,127	$0	$29,127	1.4139	$20,600
14	$0	$0	$29,127	$0	$29,127	1.4521	$20,059
15	$0	$0	$29,127	$0	$29,127	1.4913	$19,531
16	$1,666,259	$0	$29,127	$0	$1,695,386	1.5315	$1,106,984
17	$0	$0	$29,127	$0	$29,127	1.5729	$18,518
18	$0	$0	$29,127	$0	$29,127	1.6154	$18,031
19	$0	$0	$29,127	$0	$29,127	1.6590	$17,557
20	$0	$0	$29,127	$0	$29,127	1.7038	$17,095
21	$1,634,219	$0	$29,127	$0	$1,663,345	1.7498	$950,612
22	$0	$0	$29,127	$0	$29,127	1.7970	$16,208
23	$0	$0	$29,127	$0	$29,127	1.8455	$15,782
24	$0	$0	$29,127	$0	$29,127	1.8954	$15,367
25	$0	$0	$29,127	$0	$29,127	1.9465	$14,963
26	$1,609,832	$0	$29,127	$0	$1,638,958	1.9991	$819,854
27	$0	$0	$29,127	$0	$29,127	2.0531	$14,187
28	$0	$0	$29,127	$0	$29,127	2.1085	$13,814
29	$0	$0	$29,127	$0	$29,127	2.1654	$13,451
30	$0	$0	$29,127	$0	$29,127	2.2239	$13,097
Total:	$12,875,210	$0	$873,797	$0	$13,749,006		
				NPV:	$10,685,572		$10,685,572

Cost Formulas:

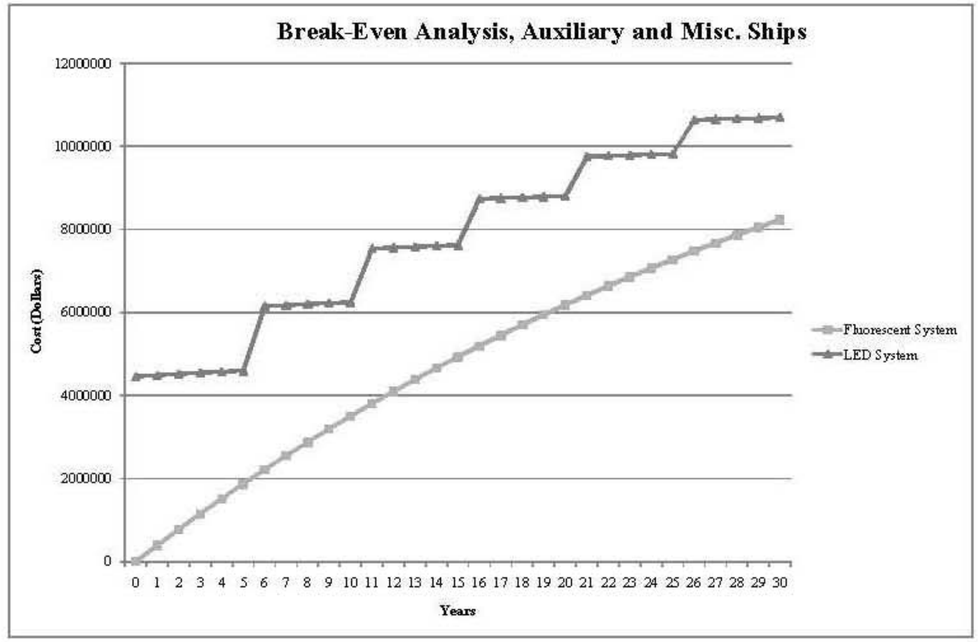
Investment: (fixtures)*(Cost per fixture)+(fixtures)*(hours to install)*(labor cost/hour)

Maintenance: (lamps replaced)*(time to replace)*(labor cost/hour)*(# of personnel)+(lamps replaced)*(cost per lamp)+(ballasts replaced)*(cost per ballast)+(starters replaced)*(cost per starter)

Operation: (gallons/hour)*(price per gallon)*(fuel burden factor)*(20 hours/day)*(days underway per year)*(number of generators-1)*5%

Disposal: (failed lamps)*(feet per lamp)*(recycle cost)

Year	FL cost, Cum PV	LED cost, Cum PV	Cum Cost Savings
0	0	$4,457,219	-$4,457,219
1	$393,138	$4,485,580	-$4,092,442
2	$775,940	$4,513,195	-$3,737,255
3	$1,148,678	$4,540,084	-$3,391,406
4	$1,511,617	$4,566,266	-$3,054,650
5	$1,865,014	$4,591,760	-$2,726,746
6	$2,209,120	$6,146,485	-$3,937,365
7	$2,544,180	$6,170,656	-$3,626,477
8	$2,870,430	$6,194,192	-$3,323,762
9	$3,188,104	$6,217,109	-$3,029,005
10	$3,497,426	$6,239,423	-$2,741,997
11	$3,798,616	$7,538,704	-$3,740,088
12	$4,091,887	$7,559,861	-$3,467,973
13	$4,377,448	$7,580,461	-$3,203,012
14	$4,655,502	$7,600,519	-$2,945,017
15	$4,926,246	$7,620,051	-$2,693,805
16	$5,189,872	$8,727,035	-$3,537,163
17	$5,446,567	$8,745,553	-$3,298,986
18	$5,696,514	$8,763,584	-$3,067,070
19	$5,939,889	$8,781,141	-$2,841,252
20	$6,176,866	$8,798,236	-$2,621,370
21	$6,407,613	$9,748,848	-$3,341,235
22	$6,632,294	$9,765,056	-$3,132,763
23	$6,851,067	$9,780,839	-$2,929,772
24	$7,064,089	$9,796,206	-$2,732,117
25	$7,271,511	$9,811,169	-$2,539,659
26	$7,473,479	$10,631,023	-$3,157,544
27	$7,670,138	$10,645,210	-$2,975,072
28	$7,861,627	$10,659,024	-$2,797,397
29	$8,048,081	$10,672,475	-$2,624,394
30	$8,229,633	$10,685,572	-$2,455,939



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$12,875,210	$0	$873,797	$0	$13,749,006	*$10,685,572*
Fluorescent	$0	$8,592,808	$3,495,186	$24,579	$12,112,573	*$8,229,633*

Assumptions:	Number of fixtures	Fixture cost	Fuel cost	Maint. Hours	Discount Rate	Shipyard labor cost / hour
	3317	$1,300.00	$2.77	0.5	0.027	$43.75

Littoral Combat Ship

Propulsion:	CODAG
Number in Service:	1
Displacement (Light Tons):	2135
Number of Fixtures:	502
Number of Lamps:	904
Fuel Burden Factor:	1
Generator GPH:	49

COST COMPARISON FOR ENTIRE CLASS:	
Lifecycle Cost of Status Quo:	$1,963,439.75
Lifecycle Cost with LEDs:	$1,838,561.14
Lifecycle Cost Savings:	$124,878.61

COST COMPARISON FOR ONE VESSEL:

	Fluorescent Lighting System							LED Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	-	-	-	-	-	-	-	$674,563	-	-	-	$674,563	1.0000	$674,563
1	$0	$35,159	$61,079	$90	$96,328	1.0270	$93,795	$0	$0	$15,270	$0	$15,270	1.0270	$14,868
2	$0	$35,159	$61,079	$90	$96,328	1.0547	$91,330	$0	$0	$15,270	$0	$15,270	1.0547	$14,477
3	$0	$35,159	$61,079	$90	$96,328	1.0832	$88,928	$0	$0	$15,270	$0	$15,270	1.0832	$14,097
4	$0	$35,159	$61,079	$90	$96,328	1.1125	$86,591	$0	$0	$15,270	$0	$15,270	1.1125	$13,726
5	$0	$35,159	$61,079	$90	$96,328	1.1425	$84,314	$0	$0	$15,270	$0	$15,270	1.1425	$13,365
6	$0	$35,159	$61,079	$90	$96,328	1.1733	$82,097	$271,672	$0	$15,270	$0	$286,941	1.1733	$244,552
7	$0	$35,159	$61,079	$90	$96,328	1.2050	$79,939	$0	$0	$15,270	$0	$15,270	1.2050	$12,672
8	$0	$35,159	$61,079	$90	$96,328	1.2376	$77,837	$0	$0	$15,270	$0	$15,270	1.2376	$12,339
9	$0	$35,159	$61,079	$90	$96,328	1.2710	$75,791	$0	$0	$15,270	$0	$15,270	1.2710	$12,014
10	$0	$35,159	$61,079	$90	$96,328	1.3053	$73,799	$0	$0	$15,270	$0	$15,270	1.3053	$11,698
11	$0	$35,159	$61,079	$90	$96,328	1.3405	$71,858	$259,186	$0	$15,270	$0	$274,456	1.3405	$204,738
12	$0	$35,159	$61,079	$90	$96,328	1.3767	$69,969	$0	$0	$15,270	$0	$15,270	1.3767	$11,091
13	$0	$35,159	$61,079	$90	$96,328	1.4139	$68,130	$0	$0	$15,270	$0	$15,270	1.4139	$10,800
14	$0	$35,159	$61,079	$90	$96,328	1.4521	$66,339	$0	$0	$15,270	$0	$15,270	1.4521	$10,516
15	$0	$35,159	$61,079	$90	$96,328	1.4913	$64,595	$0	$0	$15,270	$0	$15,270	1.4913	$10,239
16	$0	$35,159	$61,079	$90	$96,328	1.5315	$62,896	$252,174	$0	$15,270	$0	$267,444	1.5315	$174,625
17	$0	$35,159	$61,079	$90	$96,328	1.5729	$61,243	$0	$0	$15,270	$0	$15,270	1.5729	$9,708
18	$0	$35,159	$61,079	$90	$96,328	1.6154	$59,633	$0	$0	$15,270	$0	$15,270	1.6154	$9,453
19	$0	$35,159	$61,079	$90	$96,328	1.6590	$58,065	$0	$0	$15,270	$0	$15,270	1.6590	$9,204
20	$0	$35,159	$61,079	$90	$96,328	1.7038	$56,538	$0	$0	$15,270	$0	$15,270	1.7038	$8,962
21	$0	$35,159	$61,079	$90	$96,328	1.7498	$55,052	$247,325	$0	$15,270	$0	$262,595	1.7498	$150,075
22	$0	$35,159	$61,079	$90	$96,328	1.7970	$53,605	$0	$0	$15,270	$0	$15,270	1.7970	$8,497
23	$0	$35,159	$61,079	$90	$96,328	1.8455	$52,195	$0	$0	$15,270	$0	$15,270	1.8455	$8,274
24	$0	$35,159	$61,079	$90	$96,328	1.8954	$50,823	$0	$0	$15,270	$0	$15,270	1.8954	$8,056
25	$0	$35,159	$61,079	$90	$96,328	1.9465	$49,487	$0	$0	$15,270	$0	$15,270	1.9465	$7,845
26	$0	$35,159	$61,079	$90	$96,328	1.9991	$48,186	$243,634	$0	$15,270	$0	$258,904	1.9991	$129,511
27	$0	$35,159	$61,079	$90	$96,328	2.0531	$46,919	$0	$0	$15,270	$0	$15,270	2.0531	$7,437
28	$0	$35,159	$61,079	$90	$96,328	2.1085	$45,686	$0	$0	$15,270	$0	$15,270	2.1085	$7,242
29	$0	$35,159	$61,079	$90	$96,328	2.1654	$44,485	$0	$0	$15,270	$0	$15,270	2.1654	$7,052
30	$0	$35,159	$61,079	$90	$96,328	2.2239	$43,315	$0	$0	$15,270	$0	$15,270	2.2239	$6,866
Total:	$0	$1,054,772	$1,832,355	$2,711	$2,889,838			$1,948,554	$0	$458,089	$0	$2,406,643		
				NPV:	$1,963,440		$1,963,440				NPV:	$1,838,561		$1,838,561

Cost Formulas:

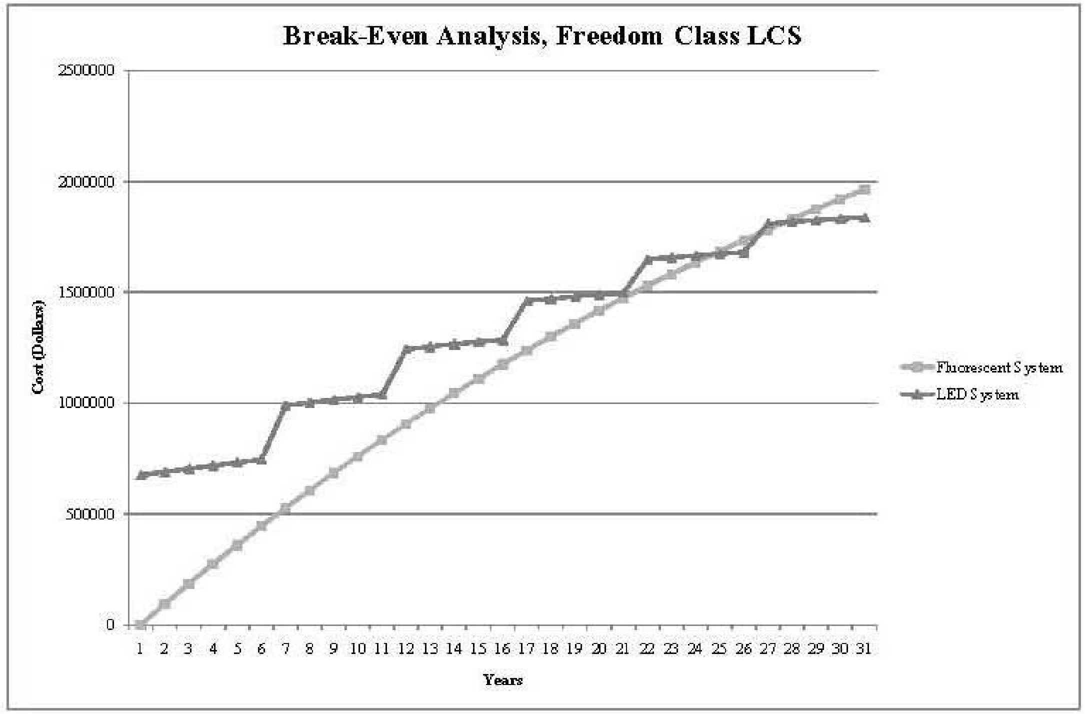
Investment: (fixtures)*(Cost per fixture)+(fixtures)*(hours to install)*(labor cost/hour)

Maintenance: (lamps replaced)*(time to replace)*(labor cost/hour)*(# of personnel)+(lamps replaced)*(cost per lamp)+(ballasts replaced)*(cost per ballast)+(starters replaced)*(cost per starter)

Operation: (gallons/hour)*(price per gallon)*(fuel burden factor)*(20 hours/day)*(days underway per year)*(number of generators-1)*5%

Disposal: (failed lamps)*(feet per lamp)*(recycle cost)

Year	FL cost, Cum PV	LED cost, Cum PV	Cum Cost Savings
0	0	$674,563	-$674,563
1	$93,795	$689,431	-$595,635
2	$185,125	$703,908	-$518,783
3	$274,054	$718,005	-$443,951
4	$360,644	$731,731	-$371,087
5	$444,958	$745,096	-$300,138
6	$527,056	$989,648	-$462,592
7	$606,995	$1,002,319	-$395,325
8	$684,832	$1,014,658	-$329,826
9	$760,623	$1,026,672	-$266,049
10	$834,422	$1,038,370	-$203,949
11	$906,280	$1,243,108	-$336,828
12	$976,249	$1,254,199	-$277,950
13	$1,044,379	$1,264,999	-$220,620
14	$1,110,718	$1,275,515	-$164,797
15	$1,175,312	$1,285,754	-$110,442
16	$1,238,208	$1,460,379	-$222,170
17	$1,299,451	$1,470,087	-$170,636
18	$1,359,084	$1,479,540	-$120,456
19	$1,417,149	$1,488,744	-$71,595
20	$1,473,687	$1,497,706	-$24,019
21	$1,528,739	$1,647,781	-$119,042
22	$1,582,344	$1,656,278	-$73,934
23	$1,634,539	$1,664,552	-$30,013
24	$1,685,362	$1,672,608	$12,754
25	$1,734,849	$1,680,453	$54,397
26	$1,783,035	$1,809,964	-$26,929
27	$1,829,954	$1,817,401	$12,553
28	$1,875,640	$1,824,643	$50,997
29	$1,920,125	$1,831,695	$88,430
30	$1,963,440	$1,838,561	$124,879



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$1,948,554	$0	$458,089	$0	$2,406,643	*$1,838,561*
Fluorescent	$0	$1,054,772	$1,832,355	$2,711	$2,889,838	*$1,963,440*

Assumptions:	Number of fixtures	Fixture cost	Fuel cost	Maint. Hours	Discount Rate	Shipyard labor cost / hour
	502	$1,300.00	$2.77	0.5	0.027	$43.75

Avenger Class MCM

Propulsion:	Diesel
Number in Service:	14
Displacement (Light Tons):	1253
Number of Fixtures:	153
Number of Lamps:	383
Fuel Burden Factor:	1
Generator GPH:	25.00

COST COMPARISON FOR ENTIRE CLASS:	
Lifecycle Cost of Status Quo:	$9,755,165.95
Lifecycle Cost with LEDs:	$7,999,070.49
Lifecycle Cost Savings:	$1,756,095.46

COST COMPARISON FOR ONE VESSEL:

Fluorescent Lighting System

Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	-	-	-	-	-	-	-
1	$0	$13,372	$20,775	$38	$34,185	1.0270	$33,287
2	$0	$13,372	$20,775	$38	$34,185	1.0547	$32,412
3	$0	$13,372	$20,775	$38	$34,185	1.0832	$31,559
4	$0	$13,372	$20,775	$38	$34,185	1.1125	$30,730
5	$0	$13,372	$20,775	$38	$34,185	1.1425	$29,922
6	$0	$13,372	$20,775	$38	$34,185	1.1733	$29,135
7	$0	$13,372	$20,775	$38	$34,185	1.2050	$28,369
8	$0	$13,372	$20,775	$38	$34,185	1.2376	$27,623
9	$0	$13,372	$20,775	$38	$34,185	1.2710	$26,897
10	$0	$13,372	$20,775	$38	$34,185	1.3053	$26,190
11	$0	$13,372	$20,775	$38	$34,185	1.3405	$25,502
12	$0	$13,372	$20,775	$38	$34,185	1.3767	$24,831
13	$0	$13,372	$20,775	$38	$34,185	1.4139	$24,178
14	$0	$13,372	$20,775	$38	$34,185	1.4521	$23,543
15	$0	$13,372	$20,775	$38	$34,185	1.4913	$22,924
16	$0	$13,372	$20,775	$38	$34,185	1.5315	$22,321
17	$0	$13,372	$20,775	$38	$34,185	1.5729	$21,734
18	$0	$13,372	$20,775	$38	$34,185	1.6154	$21,163
19	$0	$13,372	$20,775	$38	$34,185	1.6590	$20,606
20	$0	$13,372	$20,775	$38	$34,185	1.7038	$20,065
21	$0	$13,372	$20,775	$38	$34,185	1.7498	$19,537
22	$0	$13,372	$20,775	$38	$34,185	1.7970	$19,024
23	$0	$13,372	$20,775	$38	$34,185	1.8455	$18,523
24	$0	$13,372	$20,775	$38	$34,185	1.8954	$18,036
25	$0	$13,372	$20,775	$38	$34,185	1.9465	$17,562
26	$0	$13,372	$20,775	$38	$34,185	1.9991	$17,101
27	$0	$13,372	$20,775	$38	$34,185	2.0531	$16,651
28	$0	$13,372	$20,775	$38	$34,185	2.1085	$16,213
29	$0	$13,372	$20,775	$38	$34,185	2.1654	$15,787
30	$0	$13,372	$20,775	$38	$34,185	2.2239	$15,372
Total:	$0	$401,166	$623,250	$1,148	$1,025,564		
				NPV:	$696,798		$696,798

LED Lighting System

Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	$205,594	-	-	-	$205,594	1.0000	$205,594
1	$0	$0	$5,194	$0	$5,194	1.0270	$5,057
2	$0	$0	$5,194	$0	$5,194	1.0547	$4,924
3	$0	$0	$5,194	$0	$5,194	1.0832	$4,795
4	$0	$0	$5,194	$0	$5,194	1.1125	$4,669
5	$0	$0	$5,194	$0	$5,194	1.1425	$4,546
6	$82,800	$0	$5,194	$0	$87,994	1.1733	$74,995
7	$0	$0	$5,194	$0	$5,194	1.2050	$4,310
8	$0	$0	$5,194	$0	$5,194	1.2376	$4,197
9	$0	$0	$5,194	$0	$5,194	1.2710	$4,086
10	$0	$0	$5,194	$0	$5,194	1.3053	$3,979
11	$78,995	$0	$5,194	$0	$84,189	1.3405	$62,803
12	$0	$0	$5,194	$0	$5,194	1.3767	$3,773
13	$0	$0	$5,194	$0	$5,194	1.4139	$3,673
14	$0	$0	$5,194	$0	$5,194	1.4521	$3,577
15	$0	$0	$5,194	$0	$5,194	1.4913	$3,483
16	$76,858	$0	$5,194	$0	$82,052	1.5315	$53,575
17	$0	$0	$5,194	$0	$5,194	1.5729	$3,302
18	$0	$0	$5,194	$0	$5,194	1.6154	$3,215
19	$0	$0	$5,194	$0	$5,194	1.6590	$3,131
20	$0	$0	$5,194	$0	$5,194	1.7038	$3,048
21	$75,380	$0	$5,194	$0	$80,574	1.7498	$46,048
22	$0	$0	$5,194	$0	$5,194	1.7970	$2,890
23	$0	$0	$5,194	$0	$5,194	1.8455	$2,814
24	$0	$0	$5,194	$0	$5,194	1.8954	$2,740
25	$0	$0	$5,194	$0	$5,194	1.9465	$2,668
26	$74,255	$0	$5,194	$0	$79,449	1.9991	$39,743
27	$0	$0	$5,194	$0	$5,194	2.0531	$2,530
28	$0	$0	$5,194	$0	$5,194	2.1085	$2,463
29	$0	$0	$5,194	$0	$5,194	2.1654	$2,398
30	$0	$0	$5,194	$0	$5,194	2.2239	$2,335
Total:	$593,882	$0	$155,813	$0	$749,695		
				NPV:	$571,362		$571,362

Cost Formulas:

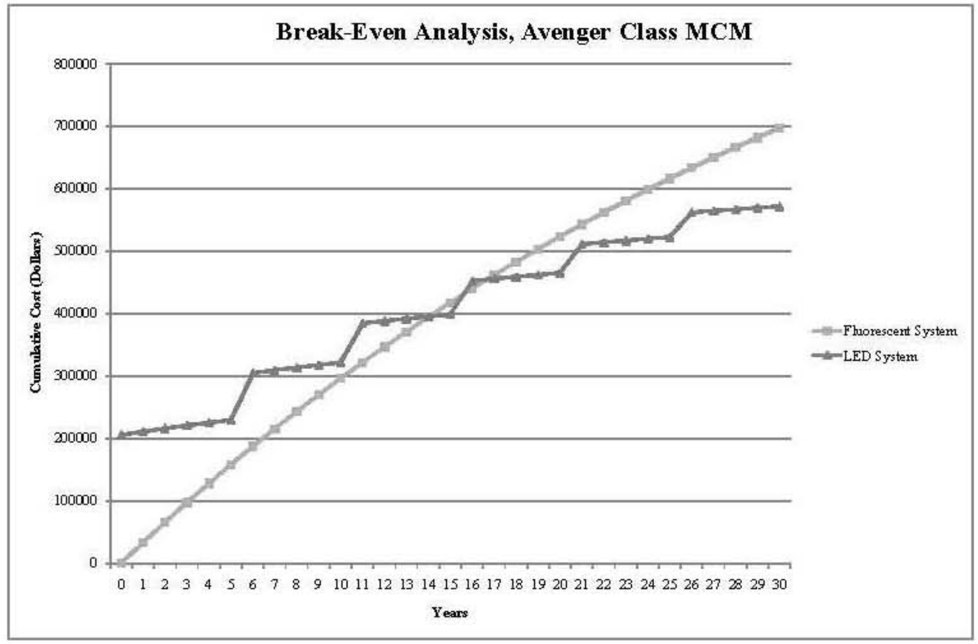
Investment: (fixtures)*(Cost per fixture)+(fixtures)*(hours to install)*(labor cost/hour)

Maintenance: (lamps replaced)*(time to replace)*(labor cost/hour)*(# of personnel)+(lamps replaced)*(cost per lamp)+(ballasts replaced)*(cost per ballast)+(starters replaced)*(cost per starter)

Operation: (gallons/hour)*(price per gallon)*(fuel burden factor)*(20 hours/day)*(days underway per year)*(number of generators-1)*5%

Disposal: (failed lamps)*(feet per lamp)*(recycle cost)

Year	FL cost, Cum PV	LED cost, Cum PV	Cum Cost Savings
0	0	$205,594	-$205,594
1	$33,287	$210,651	-$177,364
2	$65,698	$215,575	-$149,877
3	$97,258	$220,370	-$123,112
4	$127,988	$225,039	-$97,051
5	$157,909	$229,585	-$71,675
6	$187,045	$304,579	-$117,535
7	$215,414	$308,890	-$93,476
8	$243,037	$313,086	-$70,049
9	$269,935	$317,173	-$47,238
10	$296,125	$321,152	-$25,027
11	$321,626	$383,955	-$62,328
12	$346,457	$387,727	-$41,270
13	$370,636	$391,401	-$20,765
14	$394,178	$394,977	-$799
15	$417,102	$398,460	$18,642
16	$439,423	$452,035	-$12,612
17	$461,157	$455,337	$5,820
18	$482,320	$458,552	$23,768
19	$502,926	$461,683	$41,244
20	$522,991	$464,731	$58,260
21	$542,528	$510,780	$31,749
22	$561,552	$513,670	$47,882
23	$580,075	$516,484	$63,591
24	$598,112	$519,224	$78,887
25	$615,674	$521,893	$93,781
26	$632,775	$561,635	$71,139
27	$649,425	$564,165	$85,260
28	$665,639	$566,628	$99,010
29	$681,426	$569,027	$112,399
30	$696,798	$571,362	$125,435



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$593,882	$0	$155,813	$0	$749,695	***$571,362***
Fluorescent	$0	$401,166	$623,250	$1,148	$1,025,564	*$696,798*

Assumptions:	Number of fixtures	Fixture cost	Fuel cost	Maint. Hours	Discount Rate	Shipyard labor cost / hour
	153	$1,300.00	$2.77	0.5	0.027	$43.75

Cyclone Class PC

Propulsion:	Diesel
Number in Service:	10
Displacement (Light Tons):	288
Number of Fixtures:	35
Number of Lamps:	88
Fuel Burden Factor:	1
Generator GPH:	11.00

COST COMPARISON FOR ENTIRE CLASS:	
Lifecycle Cost of Status Quo:	$1,556,894.53
Lifecycle Cost with LEDs:	$1,297,765.95
Lifecycle Cost Savings:	$259,128.58

COST COMPARISON FOR ONE VESSEL:

	Fluorescent Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	-	-	-	-	-	-	-
1	$0	$3,059	$4,571	$9	$7,638	1.0270	$7,437
2	$0	$3,059	$4,571	$9	$7,638	1.0547	$7,242
3	$0	$3,059	$4,571	$9	$7,638	1.0832	$7,052
4	$0	$3,059	$4,571	$9	$7,638	1.1125	$6,866
5	$0	$3,059	$4,571	$9	$7,638	1.1425	$6,686
6	$0	$3,059	$4,571	$9	$7,638	1.1733	$6,510
7	$0	$3,059	$4,571	$9	$7,638	1.2050	$6,339
8	$0	$3,059	$4,571	$9	$7,638	1.2376	$6,172
9	$0	$3,059	$4,571	$9	$7,638	1.2710	$6,010
10	$0	$3,059	$4,571	$9	$7,638	1.3053	$5,852
11	$0	$3,059	$4,571	$9	$7,638	1.3405	$5,698
12	$0	$3,059	$4,571	$9	$7,638	1.3767	$5,548
13	$0	$3,059	$4,571	$9	$7,638	1.4139	$5,402
14	$0	$3,059	$4,571	$9	$7,638	1.4521	$5,260
15	$0	$3,059	$4,571	$9	$7,638	1.4913	$5,122
16	$0	$3,059	$4,571	$9	$7,638	1.5315	$4,987
17	$0	$3,059	$4,571	$9	$7,638	1.5729	$4,856
18	$0	$3,059	$4,571	$9	$7,638	1.6154	$4,729
19	$0	$3,059	$4,571	$9	$7,638	1.6590	$4,604
20	$0	$3,059	$4,571	$9	$7,638	1.7038	$4,483
21	$0	$3,059	$4,571	$9	$7,638	1.7498	$4,365
22	$0	$3,059	$4,571	$9	$7,638	1.7970	$4,251
23	$0	$3,059	$4,571	$9	$7,638	1.8455	$4,139
24	$0	$3,059	$4,571	$9	$7,638	1.8954	$4,030
25	$0	$3,059	$4,571	$9	$7,638	1.9465	$3,924
26	$0	$3,059	$4,571	$9	$7,638	1.9991	$3,821
27	$0	$3,059	$4,571	$9	$7,638	2.0531	$3,720
28	$0	$3,059	$4,571	$9	$7,638	2.1085	$3,623
29	$0	$3,059	$4,571	$9	$7,638	2.1654	$3,527
30	$0	$3,059	$4,571	$9	$7,638	2.2239	$3,435
Total:	$0	$91,770	$137,115	$263	$229,148		
				NPV:	$155,689		$155,689

	LED Lighting System						
Year	Investment	Maintenance	Operations	Disposal	Total	Disc. Factor	PV
0	$47,031	-	-	-	$47,031	1.0000	$47,031
1	$0	$0	$1,143	$0	$1,143	1.0270	$1,113
2	$0	$0	$1,143	$0	$1,143	1.0547	$1,083
3	$0	$0	$1,143	$0	$1,143	1.0832	$1,055
4	$0	$0	$1,143	$0	$1,143	1.1125	$1,027
5	$0	$0	$1,143	$0	$1,143	1.1425	$1,000
6	$18,941	$0	$1,143	$0	$20,084	1.1733	$17,117
7	$0	$0	$1,143	$0	$1,143	1.2050	$948
8	$0	$0	$1,143	$0	$1,143	1.2376	$923
9	$0	$0	$1,143	$0	$1,143	1.2710	$899
10	$0	$0	$1,143	$0	$1,143	1.3053	$875
11	$18,071	$0	$1,143	$0	$19,213	1.3405	$14,333
12	$0	$0	$1,143	$0	$1,143	1.3767	$830
13	$0	$0	$1,143	$0	$1,143	1.4139	$808
14	$0	$0	$1,143	$0	$1,143	1.4521	$787
15	$0	$0	$1,143	$0	$1,143	1.4913	$766
16	$17,582	$0	$1,143	$0	$18,724	1.5315	$12,226
17	$0	$0	$1,143	$0	$1,143	1.5729	$726
18	$0	$0	$1,143	$0	$1,143	1.6154	$707
19	$0	$0	$1,143	$0	$1,143	1.6590	$689
20	$0	$0	$1,143	$0	$1,143	1.7038	$671
21	$17,244	$0	$1,143	$0	$18,386	1.7498	$10,508
22	$0	$0	$1,143	$0	$1,143	1.7970	$636
23	$0	$0	$1,143	$0	$1,143	1.8455	$619
24	$0	$0	$1,143	$0	$1,143	1.8954	$603
25	$0	$0	$1,143	$0	$1,143	1.9465	$587
26	$16,986	$0	$1,143	$0	$18,129	1.9991	$9,069
27	$0	$0	$1,143	$0	$1,143	2.0531	$557
28	$0	$0	$1,143	$0	$1,143	2.1085	$542
29	$0	$0	$1,143	$0	$1,143	2.1654	$528
30	$0	$0	$1,143	$0	$1,143	2.2239	$514
Total:	$135,855	$0	$34,279	$0	$170,134		
				NPV:	$129,777		$129,777

Cost Formulas:

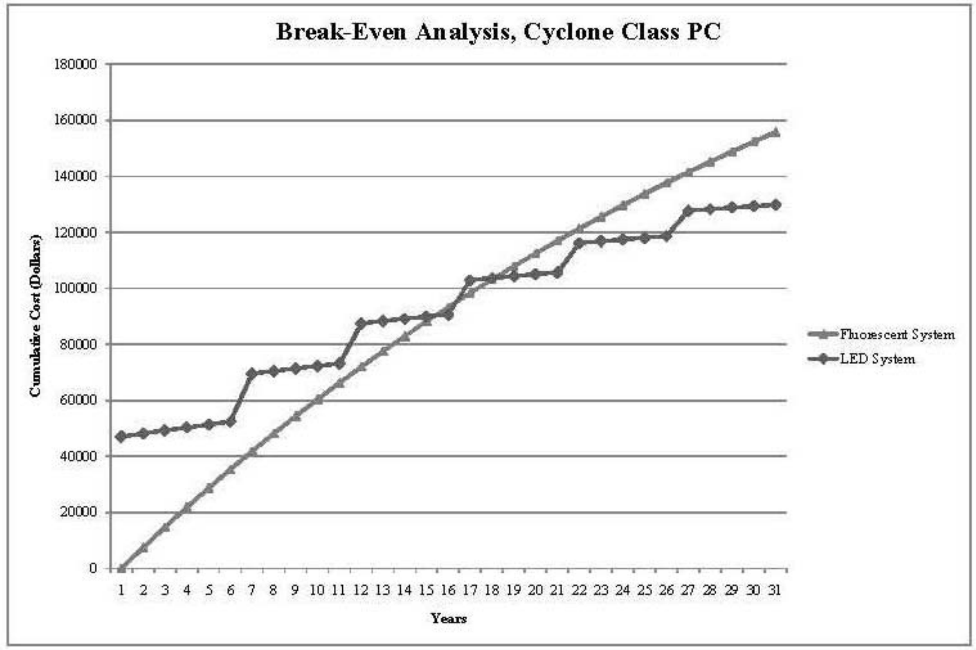
Investment: (fixtures)*(Cost per fixture)+(fixtures)*(hours to install)*(labor cost/hour)

Maintenance: (lamps replaced)*(time to replace)*(labor cost/hour)*(# of personnel)+(lamps replaced)*(cost per lamp)+(ballasts replaced)*(cost per ballast)+(starters replaced)*(cost per starter)

Operation: (gallons/hour)*(price per gallon)*(fuel burden factor)*(20 hours/day)*(days underway per year)*(number of generators-1)*5%

Disposal: (failed lamps)*(feet per lamp)*(recycle cost)

Year	FL cost, Cum PV	LED cost, Cum PV	Cum Cost Savings
0	0	$47,031	-$47,031
1	$7,437	$48,144	-$40,706
2	$14,679	$49,227	-$34,548
3	$21,731	$50,282	-$28,551
4	$28,597	$51,309	-$22,712
5	$35,283	$52,309	-$17,027
6	$41,792	$69,426	-$27,634
7	$48,131	$70,374	-$22,243
8	$54,303	$71,298	-$16,994
9	$60,313	$72,197	-$11,884
10	$66,165	$73,072	-$6,907
11	$71,863	$87,405	-$15,542
12	$77,411	$88,235	-$10,824
13	$82,813	$89,043	-$6,230
14	$88,074	$89,830	-$1,756
15	$93,195	$90,596	$2,599
16	$98,183	$102,822	-$4,639
17	$103,039	$103,548	-$509
18	$107,768	$104,256	$3,512
19	$112,372	$104,945	$7,427
20	$116,855	$105,615	$11,240
21	$121,220	$116,123	$5,097
22	$125,471	$116,759	$8,712
23	$129,610	$117,378	$12,231
24	$133,640	$117,981	$15,659
25	$137,564	$118,568	$18,996
26	$141,384	$127,637	$13,748
27	$145,105	$128,193	$16,912
28	$148,727	$128,735	$19,992
29	$152,255	$129,263	$22,992
30	$155,689	$129,777	$25,913



	Cost Factors					
System:	Investment	Maintenance	Operation	Disposal	Total	Total NPV
LED	$135,855	$0	$34,279	$0	$170,134	***$129,777***
Fluorescent	$0	$91,770	$137,115	$263	$229,148	*$155,689*

Assumptions:	Number of fixtures	Fixture cost	Fuel cost	Maint. Hours	Discount Rate	Shipyard labor cost / hour
	35	$1,300.00	$2.77	0.5	0.027	$43.75

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